Supporting Collocated and At-A-Distance Experiences with TV and VR Displays

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ABSTRACT

Televisions (TVs) and VR Head-Mounted Displays (VR HMDs) are used in shared and social spaces in the home. This thesis posits that these displays do not sufficiently reflect the collocated, social contexts in which they reside, nor do they sufficiently support shared experiences at-a-distance. This thesis explores how the role of TVs and VR HMDs can go beyond presenting a single entertainment experience, instead supporting social and shared use in both collocated and at-a-distance contexts. For collocated TV, this thesis demonstrates that the TV can be augmented to facilitate multi-user interaction, support shared and independent activities and multi-user use through multi-view display technology, and provide awareness of the multi-screen activity of those in the room, allowing the TV to reflect the social context in which it resides. For at-a-distance TV, existing smart TVs are shown to be capable of supporting synchronous at-a-distance activity, broadening the scope of media consumption beyond the four walls of the home. For VR HMDs, collocated proximate persons can be seamlessly brought into mixed reality VR experiences based on engagement, improving VR HMD usability. Applied to at-a-distance interactions, these shared mixed reality VR experiences can enable more immersive social experiences that approximate viewing together as if in person, compared to at-a-distance TV. Through an examination of TVs and VR HMDs, this thesis demonstrates that consumer display technology can better support users to interact, and share experiences and activities, with those they are close to.

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DECLARATION & CONTRIBUTING PUBLICATIONS

The research presented in this thesis is entirely the author's own work. This thesis exploits only the parts of these papers that are directly attributable to the author:

Parts of the literature review and Chapters 3, 4 and 5 were published in the journal *Personal and Ubiquitous Computing* [141]:

Mark McGill, John Williamson, and Stephen A. Brewster. 2015. A Review of Collocated Multi-User TV: Examining the changing role of the TV in the multi-viewer, multi-screen home. In *Personal and Ubiquitous Computing*. Springer London, Volume 19, Issue 5, pp 743-759. http://dx.doi.org/10.1007/s00779-015-0860-1

Parts of the literature review were published in ACM XRDS 2015 [21]:

Daniel Boland and Mark McGill. 2015. Lost in the rift: engaging with mixed reality. *ACM XRDS*, 22, 1 (November 2015), 40-45. http://dx.doi.org/10.1145/2810046

The research in Chapter 3 has been published in ACM TVX 2014 [137]:

Mark McGill, John Williamson, and Stephen A. Brewster. 2014. How to lose friends & alienate people: sharing control of a single-user TV system. In *Proceedings of the 2014 ACM international conference on Interactive experiences for TV and online video (TVX '14)*. ACM, New York, NY, USA, 147-154. http://doi.acm.org/10.1145/2602299.2602318

Video: https://www.youtube.com/watch?v=PYyBx9KWnoU

The research in Chapter 4 has been published in ACM TVX 2015 [139]:

Mark McGill, John Williamson, and Stephen A. Brewster. 2015. It Takes Two (To Co-View): Collaborative Multi-View TV. In *Proceedings of the ACM International Conference on Interactive Experiences for TV and Online Video (TVX '15)*. ACM, New York, NY, USA, 23-32. http://dx.doi.org/10.1145/2745197.2745199

Video: https://www.youtube.com/watch?v=VizRN0ggM9k

Experiment 4 in Chapter 5 has been published in ACM TVX 2014 [138]:

Mark McGill, John Williamson, and Stephen A. Brewster. 2014. Mirror, mirror, on the wall: collaborative screen-mirroring for small groups. In *Proceedings of the 2014 ACM international conference on Interactive experiences for TV and online video (TVX '14)*. ACM, New York, NY, USA, 87-94. http://dx.doi.org/10.1145/2602299.2602319

Video: https://www.youtube.com/watch?v=kJjcR1eF8us

Experiment 5 in Chapter 5 has been published in ACM TVX 2015 [140]:

Mark McGill, John Williamson, and Stephen A. Brewster. 2015. Who's the Fairest of Them All: Device Mirroring for the Connected Home. In *Proceedings of the ACM International Conference on Interactive Experiences for TV and Online Video (TVX '15)*. ACM, New York, NY, USA, 83-92. http://dx.doi.org/10.1145/2745197.2745200

Video: https://www.youtube.com/watch?v=4jqVVRmmCmA

The research in Chapter 7 has been published in ACM CHI 2015 [136]:

Mark McGill, Daniel Boland, Roderick Murray-Smith, and Stephen Brewster. 2015. A Dose of Reality: Overcoming Usability Challenges in VR Head-Mounted Displays. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 2143-2152. http://dx.doi.org/10.1145/2702123.2702382

Video: https://www.youtube.com/watch?v=SHdfxuh7_GY

The content in Chapters 6 and 8 is currently in review.

Video: https://youtu.be/WPkeabY-W9A

Education Use Consent

I hereby give my permission for this thesis to be shown to other University of Glasgow students and to be distributed in an electronic format.

Mark McGill

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“I hate television. I hate it as much as peanuts.
But I can’t stop eating peanuts.”

Orson Welles

1. INTRODUCTION

THERE has rarely been a technology so pervasive as the Television (TV). Having first reached consumer hands in 1928[1], the TV has become a common feature in households around the world, with approximately 52.2 million TVs in the UK alone [165], marginally less than the population of 64.1 million[2]. Such is the collective fixation with the TV, one is often not enough. Beyond the shared “main set” located in the living room, there might typically be TVs in other shared spaces (e.g. the kitchen) or private spaces (e.g. bedrooms or, if safety is less of a concern, bathrooms). But it is this living room TV that is of most interest, being the shared, social hub around which co-viewing, the act of synchronously viewing with others, occurs.

1.1 COLLOCATED MULTI-USER TV

TVs offer a unique shared focal point for those that cohabitate. Yet for all their prevalence in the home, these displays are still surprisingly limited with respect to multi-user use and interaction. Consider a home where the best display in the room is a large, High Definition (HD) or Ultra-HD (4K resolution) TV, positioned such that viewers anywhere in the room can attend to it comfortably. This is a standard conceit of the TV: rooms are laid out around its usage, to allow all present to view and engage with it.

Given this advantageous position, combined with size and resolution, it would be reasonable to expect the TV to have evolved to emphasize shareability and multi-user use. However, progress to this end has been faltering. For example, whilst bleeding-edge consumer smart TVs (meaning TVs with the ability to run applications and connect to the internet) now arrive

[1] www.tvhistory.tv/History%20of%20TV.htm

[2] www.ons.gov.uk/ons/guide-method/compendiums/compendium-of-uk-statistics/population-and-migrati on/index.html

with multiple separate physical remote controls, the interfaces these remote controls interact with are rarely adapted to local multi-user interaction. Instead, touchpad remotes are bundled alongside more traditional remotes, giving users a choice regarding how they interact with the TV, and providing an element of redundancy for the inevitable misplaced remote control. Similarly, whilst gestural / voice controls have become a mainstay feature, their interactions are typically directed at the singular, one-user-at-a-time TV interface. For example, a Siri search on Apple TV[3], or an Amazon Fire TV[4] voice search both interrupt on-going activity and dedicate the TV exclusively to one user's request. Fundamentally, the TV fulfils the duty of singularly presenting or browsing media content, such as satellite / cable / broadcast TV, streaming services (e.g. BBC iPlayer, Netflix, Amazon Prime), gaming consoles and the like.

This lack of development with respect to shared, multi-user use of the TV has been amplified thanks to the rise of smartphones and tablet devices. Users are no longer bound to TVs for their media needs. Instead, they can transition toward viewing and browsing on personal and private devices, whilst still attending to (often to some lesser degree) a communal TV experience. In turn, TVs have evolved to become bigger (15.8% of TVs sold in 2013 were 43 inches or greater, five years previous this was 4.5%[165]), more detailed (with 4K displays, having ~3840 pixels in horizontal resolution, now prevalent) and more immersive (with curved[5] and 3D displays). TVs have, in essence, become dedicated to the consumption of one shared experience at-a-time. A notable exception to this is that of Google Chromecast [68], a smart TV dongle released late–2013, which provides the capability for any mobile device in the room to "cast" (meaning issue playback management commands, with content streamed directly from the Internet) media to the TV. In this way, multiple users could interact with an on-going experience, or start a new experience using their mobile devices. However, even in this case, there were significant caveats e.g. browsing of media sources, web content and other activities were rendered less shareable, trapped on personal and private devices instead of occurring on the TV (until the release of screen casting functionality in late 2014).

Therefore, the research presented in this thesis firstly aimed to investigate how TVs could better support use in shared, multi-user contexts. Specifically, it was to examine how TVs could better facilitate multi-user interaction, support shared and independent multi-user use, and provide awareness of the multi-screen activity of those in the room. In doing so, this thesis would help the shared TV to better reflect the social and technological context in which it typically resides.

[3] www.apple.com/uk/tv/
[4] www.amazon.co.uk/All-New-Amazon-Fire-TV-Ultra/dp/B00UH2O6T2/
[5] www.samsung.com/uk/consumer/tv-audio-video/television/oled-tv/KE55S9CSTXXU

1.2 SYNCHRONOUS AT-A-DISTANCE TV

TV content also plays a significant role in socialising at-a-distance. The ritual of attempting to watch media content with geographically separated partners, friends, or family, with the incantation "3... 2... 1... play!", will be familiar to many [133]. The attempt to synchronize over a given communications medium, timing the press of the play button so that media sources are aligned, is commonly recanted. In news, this phenomenon has been termed "Sync-watching" [64], however it can more accurately be described as synchronous at-a-distance media consumption. The synchronous element can vary wildly with such approaches, with buffering of streams, pauses in playback, and shifts in attention all affecting geographically separated viewers' relative positions in a shared media experience. The at-a-distance element too varies, from cross-residential friends at opposite ends of a city, to partners on different continents. The net effect, however, is invariably the same: in using technology to communicate and share media experiences synchronously at-a-distance, those that are geographically separated become closer to those they watch with [133], and engender greater intimacy [41] in their relationships.

The importance of this effect becomes apparent when the scale of one particular demographic is considered: couples in long-distance relationships. In the USA alone, there are estimated to be 7 million couples in long-distance relationships, with census data from 2005 suggesting that there are approximately 3.6 million married persons who live apart "for reasons other than marital discord"[6], e.g. because of economic migration or education. Indeed, as many as 75% of students in the USA are likely to have taken part in a long-distance relationship during their college education [201]. This is a significant portion of the population for whom technology facilitating at-a-distance synchronous media experiences could strengthen their relationships. Indeed, those that are more technologically savvy already engage in such activity, for example using web-based services such as *rabb.it* or *togethertube.com*, relying on synchronized broadcast TV content when in the same country or region, or more bespoke solutions such as synchronizing playback of Netflix content over Skype.

These behaviours have been readily and repeatedly witnessed in research [159, 41]. The fact that this ritual of synchronization is prevalent is testament both to the rise in on-demand TV, and to how this scenario is insufficiently supported by technology. Socialising anonymously on the Internet (e.g. using *twitch.tv)* is often easier than watching a specific program, with a specific person, at the same time synchronously at-a-distance. Yet whilst the impact of at-a-distance experiences is well known, smart TV platforms have yet to embrace a means of facilitating such experiences. Thus, the research presented in this thesis secondly aimed to investigate how TVs could support synchronous at-a-distance TV media experiences, lower-

[6]www.longdistancerelationships.net/faqs.htm#How_common_are_long_distance_relationships

ing the barrier for entry to such experiences and making them more accessible to those whose lives and relationships could best benefit, turning the TV into a shared space at-a-distance.

1.3 COLLOCATED AND AT-A-DISTANCE VR

Whilst TVs are typically the most immersive means of consuming video content in the home, this *status quo* is being threatened by VR HMDs. Having already seen their usage eroded by mobile device streaming, VR HMDs now threaten to supplement, or even supplant, TVs for some forms of media due to their capability for 360° immersive experiences. This presents a significant caveat to TV research.

The possibility of VR HMD adoption has been hinted at for decades [100]. Historically, their adoption has been restricted due to the low fidelity of VR experiences (both with respect to rendering and display technology) and, perhaps most restrictively of all for consumers, cost. However, advances in small form factor displays (e.g. the high refresh rate, low persistence, and high definition panels typically used in mobile devices) demonstrated that high fidelity VR HMDs were now not only technologically feasible, but a viable and affordable consumer reality. This was exemplified with the Oculus Rift DK1 Kickstarter campaign[7], which delivered $300 VR HMDs into developer (and consumer) hands by mid-2013. What followed has seen the likes of Samsung (Gear VR[8]), Sony (Morpheus / Playstation VR[9]), HTC / Valve (Vive[10]), Oculus / Facebook (DK 1/2, CV 1[11]), and Google (Cardboard[12]) battling to be the leader in this VR renaissance, and a variety of headsets are expected to be widely available in 2016. Thus VR HMDs can reasonably expect to see significant home adoption in the near future.

But there remain a number of sizeable problems in trying to deliver a VR experience that is usable in the real "consumer" world. These displays exacerbate the problem of collocated socialization, thanks to a very obvious quality: in wearing a VR HMD, the real world is occluded by the virtual, at the benefit of a user's immersion, but at the cost of being unaware of, and unable to interact with, reality. Thus, even being aware of the presence of others becomes problematic. However, combined with room wide sensing, VR HMDs also have the capability to display shared mixed-reality social experiences, where those the wearer is communicating with, be they in the same room or at-a-distance, appear to be in the same space as themselves. Thus, the research presented in this thesis thirdly aims to investigate

[7] https://www.kickstarter.com/projects/1523379957/oculus-rift-step-into-the-game/description
[8] http://www.samsung.com/global/galaxy/wearables/gear-vr/
[9] https://www.playstation.com/en-gb/explore/ps4/features/playstation-vr/
[10] https://www.htcvive.com/us/
[11] https://www.oculus.com/en-us/
[12] https://www.google.co.uk/get/cardboard/

how VR HMDs could support collocated socialization when consuming immersive, private experiences, and synchronous at-a-distance use in shared experiences.

1.4 Research Questions

This thesis aims to answer the following questions:

RQ1 - Chapter 3 Are existing single-user TV interfaces suitable for multi-user use?

RQ2 - Chapter 4 How can TVs support both shared and independent use?

RQ3 - Chapter 5 Can TVs provide an awareness of others' collocated multi-screening activity without disrupting existing usage?

RQ4 - Chapter 6 How can TVs support synchronous at-a-distance use with a partner?

RQ5 - Chapter 7 Should VR HMDs provide the ability to be aware of, and engage with, others in the same room, and how?

RQ6 - Chapter 8 How are VR HMDs likely to change the nature of synchronous media consumption at-a-distance?

1.5 Thesis Statement

This thesis asserts that TVs and VR HMDs can better support social and shared use, in both collocated and at-a-distance contexts. For collocated TV, this thesis demonstrates that the TV can be augmented to support multi-user interaction, enable independent and shared multi-user use, and provide an awareness of the multi-screen activity of those in the room. For at-a-distance TV, shared activities can be enabled using existing smart TVs and smart phones, broadening the scope of shared experiences beyond the four walls of the home. For VR HMDs, collocated proximate persons can be brought into mixed reality VR experiences based on engagement, improving VR HMD usability. Applied to at-a-distance interactions, these shared mixed reality VR experiences can provide more immersion, and allow for socialising that more closely resembles viewing together in person, compared to at-a-distance TV.

1.6 THESIS WALKTHROUGH

Chapter 2, *Literature Review*, examines pertinent literature firstly on collaboration in collocated groups (Section 2.1). Why is collaboration conducted, how have computers supported collaboration, and what role does awareness play in facilitating effective collaboration. The role of the TV is then discussed (Section 2.2). Why do people watch TVs, how do they share use of TVs, and how has the proliferation of mobile devices affected usage of the TV. Consumption of TV content at-a-distance (Section 2.3) is then examined, through both social TV at-a-distance, and the positive effect synchronous at-a-distance media consumption has been shown to have in long-distance relationship maintenance. Finally, VR HMDs and mixed reality are discussed (Section 2.4), with a focus on why VR HMDs are seeing a resurgence, problems using VR HMDs in shared settings, their use in at-a-distance communication, and applications of augmented virtuality / mixed reality to these domains.

Chapter 3, *Shared Control of the TV*, reports on an "Existing Behaviours Survey" (Section 3.1) examining how control of shared TVs is currently managed. It then discusses Experiment 1 (Section 3.2), looking at mechanisms by which control of an grid-based Electronic Programme Guide (EPG) interface can be mediated and shared in small groups. This chapter answers RQ 1.

Chapter 4, *Shared Use of the TV*, reports on Experiments 2 and 3, examining how multi-view display technology (meaning a separate physical view for each user) can be used to allow for both independent and shared use of a TV. Experiment 2 (Section 4.1) compares an Android-based two-user smart TV against both multi-screen and multi-view displays in a collaborative movie browsing task. Based on the findings in this study, Experiment 3 (Section 4.2) iterates on this by giving users the ability to transition between casual (viewing both views) and focused (viewing only one view) modes of usage, and dynamically set their engagement with other users' activities. This work provides a foundation for multi-user multi-view smart TVs that can support collaborative, shared and independent activity on a single shared TV. This chapter answers RQ 2.

Chapter 5, *Appropriating the TV for Multi-Screen Activity*, describes Experiments 4 and 5, firstly examining how awareness of multi-screen activity (i.e. mobile / tablet devices) can be provided through the TV, and secondly examining how disruptive such usage of the TV is to existing viewing, and how awareness of ongoing activity in the same space can be provided non-disruptively. Experiment 4 (Section 5.1) looks at the extent to which multi-screen activity can be made more accessible to others, through utilizing the TV as a shared focal point upon which multi-screen activity can be displayed. Experiment 5 (Section 5.2) builds upon this work by investigating how disruptive shared, mirrored usage of the TV display can be to existing TV viewing, and examines ways to mitigate against this disruption given a multi-view capable TV, allowing for non-disruptive awareness of multi-screen activity occurring in the same room. This chapter answers RQ 3.

Chapter 6, *Synchronous At-A-Distance Use of the TV*, describes the implementation (Section 6.1) of *CastAway*, a system for supporting at-a-distance synchronous TV experiences on an existing smart TV platform (Google Chromecast) using existing applications. Experiment 6 (Section 6.2) describes the evaluation of CastAway in-the-wild by five couples at-a-distance. This chapter answers RQ 4.

Chapter 7, *Usability Of VR HMDs*, firstly describes a survey (Section 7.1) into the significance and prevalence of usability impediments such as being unable to see interactive objects or proximate persons. Section 7.2 then provides an overview of a generalized solution to some of these impediments created in collaboration with Daniel Boland, in the form of Engagement-Dependent Augmented Virtuality, where reality can be selectively incorporated as and when necessary based on inferred user engagement with reality. It then presents a study, Experiment 7 (Section 7.3), examining how the concept of Engagement-Dependent Augmented Virtuality can be applied to the presence of others in the same room. This chapter answers RQ 5.

Chapter 8, *At-A-Distance Media Consumption Using VR HMDs*, describes Experiment 8 (Section 8.1) examining how VR HMDs can enable shared and synchronous at-a-distance VR experiences. Shared immersive experiences are compared to physically co-viewing together, and co-viewing together at-a-distance using the TV for both viewing and communication. This chapter answers RQ 6.

Chapter 9, *Discussion and Conclusions*, reviews and summarises the research in this thesis, discussing the novel contributions made, and how each research question was answered in turn. Limitations of the research are discussed, and avenues of follow-up research building upon this work proposed.

2. Literature Review

This chapter reviews the existing literature related to the Research Questions, specifically examining work regarding collaboration, TV use, and VR HMDs. The review begins by examining collaboration and sharing in collocated intimacy groups in Section 2.1. This section first looks at the role awareness plays in being able to collaborate; what is awareness, why does it aid collaboration, how is it come by and facilitated through technology, and what kinds of awareness are necessary during collaboration. Engagement is then presented as a theoretical underpinning for how attention and awareness can be managed, through the casual–focussed continuum [175], with engagement being the extent to which a person wishes to attend to, or have awareness of, a given activity. This section then discusses relevant examples of computer supported collaboration and sharing, before ending in a discussion of the psychology and makeup of groups that collaborate.

Section 2.2 surveys the social importance of the TV, and how the role of the TV has changed given the advent of multi-screening. The outcome of this is a reasoning as to why multi-user use of the TV should be explicitly designed for and facilitated, and a discussion as to how this might be accomplished (RQ 1, 2 and 3).

Section 2.3 then discusses how the social role of the TV need not be contained to the four walls of the living-room, by examining how synchronous media consumption can help to maintain and support relationships at-a-distance, through shared and synchronous media consumption combined with computer mediated communications (RQ 4).

Section 2.4 finally reviews the resurgence of VR HMDs, and their potential to supplement, or in some cases supplant, the TV when consuming immersive media experiences. This section then reviews how mixed reality can be used to incorporate elements of reality in virtuality, and examines existing usability issues and the potential roles that VR HMD may fill in the home and at-a-distance (RQ 5 and RQ 6).

Finally, the chapter ends with a summary of the most important outcomes from this review, which have shaped the Research Questions and so provide context for the contributions of this thesis.

2.1 COLLOCATED COLLABORATION AND SHARING

2.1.1 WHY DO PEOPLE COLLABORATE?

Collaboration is the means by which a group can work together to achieve a shared goal or aim. Whilst collaboration is often a focus of Computer-Supported Cooperative Work (CSCW), collaboration can occur in many contexts outside of work. For example, collaboratively searching for entertainment [151], such as trying to find a movie to watch together, could be conceptualized as a loosely-coupled collaborative task (meaning there is a degree of autonomy between those in the group) [173]. In searching for a movie to watch, people can browse independently (e.g. using phones and tablets) or together (e.g. using a smart TV), and can transition between shared and independent activity as they see fit, given the correct tools and technological support. Such tasks can be performed independently or together, but the eventual outcome (e.g. having to select an acceptable movie for the group) necessitates collaboration, and collaboration is the means toward reaching this outcome quickly and efficiently (according to whatever decision scheme they are employing, as will be discussed in Section 2.1.5.4).

Collaboration frequently occurs through search activities. Morris [149] first surveyed collaborative web search practices in 2008 through a survey ($n = 204$) distributed to Microsoft employees. Of these respondents, 53.4% had cooperated with other people to search the web, with 86.1% having conducted collocated cooperative searches, typically with small groups of two (80.7%) to three or four (19.3%) people. The search activities they tended to conduct included travel planning (27.5%), shopping (25.7%), and social planning (12.8%). In 2009 Morris *et al.* [6] found that, of the collocated searches that occurred in the home, 58% were informational searches, with the majority of searches being spontaneous (70.6%) and lasting only a few minutes (64.7%), occurring in pairs (70.6%) or groups of three or four family members or friends (29.4%). Most searches were conducted using a single, shared machine (laptop/desktop) (76.5%). Morris revisited this topic in 2013 [151], this time surveying members of the public ($n = 167$), finding that 65.3% had performed collaborative search, for topics such as news and current events, travel, entertainment, restaurants and social events. These papers affirmed the prevalence of collocated synchronous collaborative search in small groups in everyday life, with technology, in the form of PCs, phones and tablets, playing a significant role in facilitating this behaviour.

2.1.2 AWARENESS

The role of technology in collaboration is not, however, limited to providing each user with a conduit for search activity to occur. Technology can also facilitate more efficient collaboration, through providing shared awareness of activities and actions, and through utilising interfaces, displays and interaction techniques that better support cooperation. Awareness in CSCW is a broad (and at times problematic [189]) term that encapsulates various types of group awareness, be it being aware of who is there, what they are doing, what they are interacting with, what their focus of attention is, or even what their awareness of you is. It is a cornerstone of collaboration [50] and coordination [12], providing "an understanding of the activities of others, which provides a context for your own activity" [50].

For nearly three decades, the concept of awareness has been explored in CSCW and HCI. A variety of definitions, models, and frameworks have been theorised and investigated in that time, continually redefining what awareness means. Whilst the definition of CSCW implies that research within this area is oriented toward collaboration in the workplace, it has been widely recognised that this name is no longer accurate, with parts of the CSCW community rightly pointing out that:

> "'Computer Supported Cooperative Work' has lost its relevance. Computers are no longer the only digital device of interest... Digital technology is no longer confined to a support role... The focus was initially on small groups for which cooperation was the norm, but today's digital world features hacker attacks, spam, privacy concerns, conflict, and competition.... In 1985 systems capable of supporting groups were mainly affordable in corporate work settings. It's different now." [77]

This is reflective of the contribution made in areas such as awareness: whilst concepts arose within the context of workspace collaboration, these concepts are often broadly applicable to a variety of other contexts, and it is given this view that relevance is found in applying workplace concepts of awareness to collaboration and cooperation in the home.

2.1.2.1 ORIGINS

The concept of awareness has been defined and redefined repeatedly during the lifetime of CSCW (see [178, 75] for in depth historical overviews of the field). Awareness was first introduced within the auspices of workplace collaboration; early work in CSCW centered around examining how collaboration was conducted, how existing processes succeeded or failed in facilitating collaboration, what interactions occurred between collaborators, and what effect environmental factors and context had on the ability to collaborate. For example Kraut *et al.* [116] examined scientific collaboration, finding that physical proximity was significant factor in determining whether collaboration arose. They stated that "increased awareness of the attributes of one's neighbours allows one to choose partners judiciously".

This work motivated the beginnings of awareness research, specifically in the areas of "media spaces", a means toward replacing the need for physical proximity by employing shared audio and visual spaces. Such spaces enabled informal awareness, the knowledge of who is around and what they are doing. Often the aims were to overcome the barriers to collaboration that distance introduced. The first media space developed by Xerox PARC [205] was used as a means toward linking offices which did not have adjoining commons areas, by utilizing idle teleconferencing equipment to provide permanent video feeds which maintained background contact with other offices and allowed for informal interactions (i.e. unplanned, unscheduled, *ad hoc*) to take place. Research into media spaces quickly converged on a consistent concept:

> "To support informal interactions, people need to be aware of others' presence, activities, and availability" [178].

In formalizing the concept of awareness, there arose three methodologies / frameworks that are most pertinent to this thesis, which will be discussed in turn: event-based awareness, spatially-based awareness, and workspace awareness.

2.1.2.2 Event-Based Awareness

Event-based awareness offered a markedly different way of garnering awareness compared to persistent and shared media spaces. Instead, users could state the kinds of information they were interested in, and have this information delivered directly and discretely, for example via audio notifications, whilst unwanted information was filtered out. This was first formalised in the Khronika system [130] where senders and receivers of notifications were effectively decoupled allowing for the events generated by senders to be forwarded only to interested participants. This was then extended by Fuchs *et al.* in the "Event-Pipeline Model" [60], where additional filtering capabilities were introduced, for example allowing the senders of events to set appropriate levels of privacy which would then be automatically enacted by privacy filters before the event information was utilized further.

2.1.2.3 Spatially-Based Awareness

A more extreme example of decoupling the senders and receivers of events came about in the form of the COMIC awareness model [15] which relied on a spatial metaphor for determining awareness:

> "Control (is) given to the provider as well as the recipient – the provider controls their nimbus, or the information they are sending, and the recipient controls their focus, or how they pay attention to the information around them" [178].

The application area for their work was in immersive 3D worlds, with a users awareness of objects being based on their focus, and on the reach of an object's nimbus, but this concept hints at a property that will be revisited in subsequent chapters of this thesis. To have awareness two conditions must be met: the system must provide the capability to become aware, and the user must choose to use this capability. Moreover, awareness is not binary; there are degrees of awareness. A system might unobtrusively provide only some pertinent details to minimize cognitive load, or it might provide a complete view of others' activities, and in both cases the user retains the capability to vary their attention to what is provided.

2.1.2.4 WORKSPACE AWARENESS: "WHAT YOU SEE IS WHAT I DO"

Arguably the most influential work in this area was in defining the types of awareness that could arise in group contexts. Gutwin and Greenberg [79] defined group awareness as:

> "The up-to-the-minute knowledge of other people's activities that is required for an individual to coordinate and complete their part of a group task. Group awareness is maintained by keeping track of information such as other participants' locations in the shared space (where are they working?), their actions (what are they doing?), the interaction history (what have they already done?), and their intentions (what are they going to do next?)" [79]

This definition aligned with prior research into awareness, for example Dourish and Belotti [50] defined it as "an understanding of the activities of others, which provides a context for your own activity". The key difference was in how Gutwin and Greenberg summarised the individual aspects of group awareness, in terms of informal awareness, group-structual awareness, social awareness, and workspace awareness [81].

Informal awareness referred to the knowledge of who is around and what they are doing, "the glue that facilitates casual interaction". A notable example of this was in Greenhalgh and Benford's work [73] regarding collaborative 3D spaces, where awareness was quantifiably based on the user's view of the object of their awareness. If the object was in the periphery of their view, they would have a lower awareness due to a lower potential to receive information from it.

Social awareness referred to "information that a person maintains about others in a social or conversational context", essentially the social signal processing [223, 224] innately performed to understand and interact with others in shared spaces. There have been systems that have exploited and exposed these social cues, for example through providing gaze awareness [105].

Group-structural awareness referred to knowledge about the roles, responsibilities, statuses, and positions on issues within groups; essentially examining group hierarchies and social decision schemes (see Section 2.1.5.4) from a workplace perspective.

Element	Relevant Questions
Identify	Who is participating in the activity?
Location	Where are they?
Activity Level	Are they active in the workspace?
	How fast are they working?
Actions	What are they doing?
	What are their current activities and tasks?
Intentions	What are they going to do?
	Where are they going to be?
Changes	What changes are they making?
	Where are the changes being made?
Objects	What objects are they using?
Extents	What can they see?
Abilities	What can they do?
Sphere of Influence	Where can they have effects?
Expectations	What do they need me to do next?

Table 2.1: Initial definition of elements of workspace awareness, be they past, present, or future [81].

The final aspect discussed was that of workplace awareness, the most relevant to this thesis. Workplace awareness referred to maintaining knowledge about "others' interaction with the space and its artifacts". Workspace awareness was broken down into a number of elements, as seen in Table 2.1, consisting of aspects of current and past activity which constituted workspace awareness. Gutwin and Greenberg additionally described how this awareness was obtained, suggesting that information could be gathered through:

Direction Communication e.g. Explicitly communicating information about their activity.

Indirect Productions e.g. Actions that are intentionally publicly available that convey information about their activity.

Consequential Communication e.g. observing or listening to activity.

Feedthrough e.g. observing the effects someone's actions have on shared artifacts.

Environmental feedback e.g. indirect or abstract measures which are impacted by other's activity

They applied aspects of these concepts to a series of widgets for conveying workspace awareness. Of significant note amongst these was the "What You See Is What I Do" widget whereby the screen space around other user's cursors was captured and presented to collaborators, allowing them to have a continuous but limited insight into their activity presented on their display, with the rest of the display allotted to their own task view, as seen in Figure 2.1. This is notable because it gave users the ability to determine what portion of their own workspace was dedicated toward providing an awareness of other's activity (identity, location, and actions) albeit with a deliberately limited view of said activity.

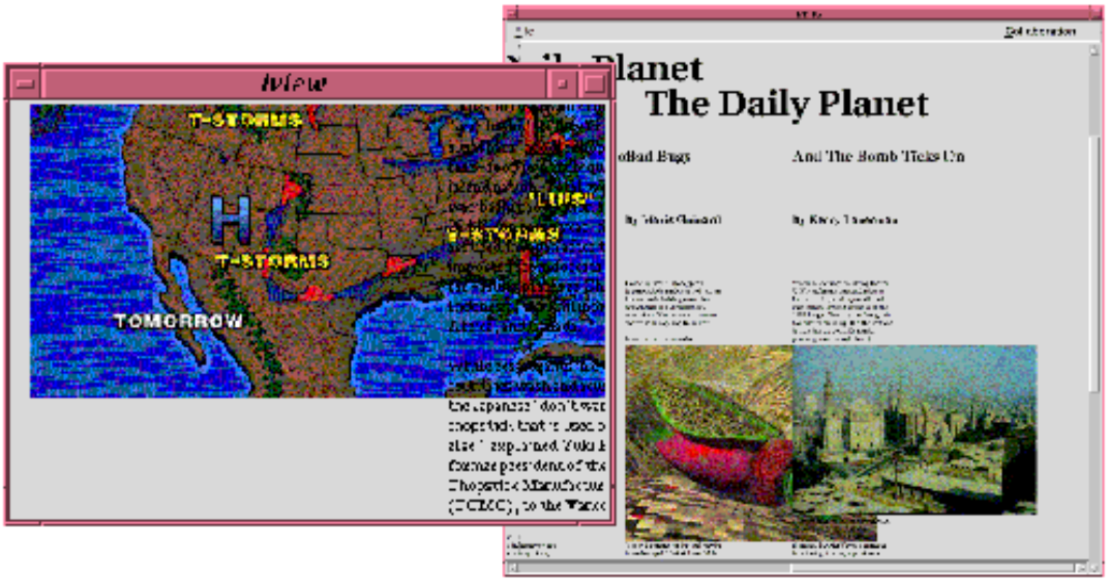


Figure 2.1: Gutwin and Greenberg's [81] "What You See Is What I Do" widget. The left window displayed the area directly around the remote user's cursor to the local user, whilst the right window was the portion of the local user's display left over for their primary task view.

This view of workspace awareness was further refined, most notably by Greenberg and Gutwin [80] and Schmidt [189]. Greenberg and Gutwin [80] specifically elaborated on elements related to work in the present (see Table 2.2) and the benefits of workspace awareness (see Table 2.3).

Of particular note are the subsets of workspace awareness regarding what users are doing: action and artifact awareness both rely on direct knowledge of the activity of others, be it abstracted in some form (e.g. "they are browsing horror movies") or direct (e.g. being able to view the activity of browsing horror movies as it is conducted). Of further note are the aspects of view and gaze: should an observed user be aware that you are currently focussed

Category	Element	Specific questions
Who	Present	Is anyone in the workspace?
	Identity	Who is participating? Who is that?
	Authorship	Who is doing that?
What	Action	What are they doing?
	Intention	What goal is that action part of?
	Artifact	What object are they working on?
Where	Location	Where are they working?
	Gaze	Where are they looking?
	View	Where can they see?
	Reach	Where can they reach?

Table 2.2: Refined definition of elements of workspace awareness relating to the present [80].

Activity	Benefit of workspace awareness
Management of coupling	Assists people in noticing and managing transitions between individual and shared work.
Simplification of communication	Allows people to use the workspace and artifacts as conversational props, including mechanisms of deixis, demonstrations, and visual evidence.
Coordination of action	Assists people in planning and executing low-level workspace actions to mesh seamlessly with others.
Anticipation	Allows people to predict others' actions and activity at several time scales.
Assistance	Assists people in understanding the context where help is to be provided

Table 2.3: Benefits of workspace awareness [80].

on their activity? Perceived visibility [19] has been shown to have a significant affect on awareness checking behaviour for example, with users likely to check a partner's display more often when they believe their partners do not know that they are checking, or when the task is time-constrained. And to what extent should you be able to focus on their activity, for example only receiving a subset of their view as previously discussed with the WYSIWID widget, or perhaps duplicating views entirely, either in miniature (e.g. an over-the-shoulder view [81]) or in full (e.g. relying on view slaving to switch to another person's view in full detail [81, 80]).

These concepts have been taken to extremes in recent years, for example Tee *et al.* [207] facilitated artifact awareness through screen sharing for distributed groups, whereby portions of others' screens were conveyed in miniature, with the ability to selectively raise larger views of a screen to get more detail, as well as the ability to engage in remote pointing. They found that, in addition to the benefits outlined in Table 2.3, facilitating this type of awareness increased the possibility of serendipitous interactions (derived from casual interaction theory [116], an examination as to the effect of physical proximity on work and cooperation), be they conversation or collaboration.

2.1.2.5 TECHNOLOGY, DESIGN TENSIONS, AND PRIVACY

A systematic review of awareness technology by Gross [74] broadly categorised the underlying systems in terms of either facilitating coexistence awareness ("users' mutual person-oriented information on each other") and cooperation awareness ("users' mutual information on their activities – either as background information in a collaborative working environment, or as foreground information in a cooperative application"). Systems that exemplified coexistence awareness approaches included media spaces and collaborative virtual environments, whilst cooperation awareness was exemplified by systems such as shared workspaces, or group editors.

The technologies that underpinned these systems were categorised as awareness information environments (analogous to the event notification framework discussed previously), sensing technology (capturing the data used to support the awareness technology whilst taking into account privacy for example), awareness information presentations (presenting this awareness information graphically, ambiently etc.) It is upon these technologies that models (like the previously mentioned Workspace Awareness Model) are applied.

In sensing events, and exposing information regarding activity, there are also issues regarding how to determine whether said data needs to be censored or blocked on the basis of privacy concerns. Gross [74] stated the "design tension is the antagonism between sharing awareness information and maintaining privacy", citing Hudson and Smith's [99] salient point that "the more information transmitted, the more potential for violation of one's privacy".

Early approaches to ensuring privacy violating details were removed utilized transformations of what was being conveyed. For example Hudson and Smith [99] modified video footage such that instead of conveying a full view of the person on the video, blocky shadows took their place, superimposing these shadows on a still image of the room they were in. More abstract representations were also utilized, for example Pedersen and Sokoler [170] conveyed information regarding activity or how many people were present through drifting clouds, mechanical toys, and temperature. Others removed privacy violating details, for example Junestrand *et al.* [108] developed a conceptual home with public and private zones for facilitating video communication, whereby anything outwith a public zone would be filtered out from the video feed, and shared awareness was only facilitated in public zones. In these ways information could be selectively filtered. However, this filtering can also be achieved through an element of obfuscation or blurring. For example, Tee *et al.* [207] allowed users to screen-share at a given resolution, thus users frequently shared at a significantly lower resolution that their display was operating at to intentionally obscure what was being communicated, whilst also finding that users wanted the ability to selectively filter or obscure elements of the display space. Interestingly, they also found that some multi-monitor users would dedicate one of their displays to be the shared presentational display, thus artifacts that they were willing to share awareness of were often moved onto this monitor, whilst the other monitor remained private.

Whilst the utility of filtering through blurring for preserving privacy has been previously questioned [160], techniques such as filtering or blurring offer the possibility of controlling the amount of awareness that is possible. Models and frameworks have been designed that attempt to rectify this privacy problem, for example Palen and Dourish [167] suggested that:

> "Privacy management is a dynamic response to circumstance rather than a static enforcement of the rules; that it is defined by a set of tensions between competing needs; and that technology can have many impacts, by way of disrupting boundaries, spanning them, establishing new ones, etc." [167]

They discussed privacy in social psychology terms, framing privacy as the tensions between multiple boundaries: disclosure (what a person chooses to disclose or withhold, what they are required to disclose etc.), identity (the boundary between self and other, examining privacy as a social phenomenon, so for example what a person makes public in certain contexts, and how they choose to present or modify this information) and temporality (persistence of actions and information, and how privacy is taken into account in terms of past / present / future).

Boyle and Greenberg [23] took an interdisciplinary approach to the description and facilitation of privacy, with the *Privacy Grounding Model* [182] building upon this work, suggesting the design of signalling and grounding mechanisms in awareness applications. They demonstrated an instant-messaging implementation where users could, for example, signal they had attended to a received message but declined to respond until later, without requiring further interaction to convey why this was the case, or when they would respond, an approach that supported "autonomy on the basis of ambiguity".

There are also issues regarding whether or not the exposed information, privacy filtered or not, should be conveyed as is, or be manipulatable:

> "There is an implicit assumption in much awareness research that people desire accurate information about others, and to convey accurate information about themselves. We believe this assumption to be problematic... In communication, people frequently draw on the ambiguous properties of certain media to maintain plausible deniability about having received messages at all, avoid confrontation about possible threats to self-presented identity, as well as to encourage or discourage rapid response to a query" [83]

Hancock *et al.* [83] suggested that within the scope of communicating awareness there lies significant ambiguity: people are inherently quite good at manipulating what they convey to others as and when necessary, whilst Tee *et al.* [207] framed this in terms of disinformation (intentionally inaccurate information). Hancock *et al.* proposed "butler lies" as one of the ways in which this information is often manipulated, describing them as "lies that allow for the polite initiation and termination of conversations", whilst Tee *et al.* suggested that this represented self-appropriation or self-scrutiny: "people monitor what they are sharing and manage the impression that they give to others".

From privacy, to ambiguity, to outright lies, the question as to what should be communicated regarding an awareness of others is not straightforward to answer. Whilst sensing technology or view-slaving can provide absolute precision and detail regarding activity, users may wish to censor that communication, filter or blur it, augment and modify it, or even discard it and provide entirely different information, and these capabilities can be designed for or can arise through user appropriation of a given system. Additionally this information may be unwanted in the first place, and thus significant thought must be given to both what is available to be made aware of, and how to enable users to selectively engage or ignore this information to the degree required. This tension between providing awareness whilst maintaining privacy is widely applicable to other contexts. For example, if given the capability to share your personal TV viewing habits with others, to what detail would it be acceptable to share? Is it sufficient to show what programs were watched, or when they were viewed? How this tension is resolved is a function of many things e.g. the control given over what is shared, the capability for privacy filtering, the context of use, with whom information is being shared etc. Thus there is no one universal answer; instead, this tension must be resolved uniquely for each awareness system.

2.1.2.6 ATTENTION AND ENGAGEMENT

> "The very word "awareness" is one of those highly elastic English words that can be used to mean a host of different things. Depending on the context it may mean anything from consciousness or knowledge to attention or sentience, and from sensitivity or apperception to acquaintance or recollection" [189]

Schmidt [189] summarised a number of problems with awareness in CSCW, for example in terms of its diversity of use and meaning (e.g. 'passive awareness', 'background awareness', 'mutual awareness' etc.) of which this literature review has illustrated only a few, and in terms of the relationship between the definition of awareness, and the concept of attention:

> "Whereas awareness... is conceived of and defined in terms of 'focus', other CSCW researchers emphatically distinguish the phenomenon of 'awareness' from 'attention' or 'focus' by defining awareness as 'information' that 'is being gathered passively, while other workplace activities progress' " [189]

Schmidt took issue with the lack of understanding CSCW research had regarding what users, referred to as actors, displayed to the world, and what they perceived or monitored, and how this related to the "tunnel vision" concept of focus and attention, positing a number of Research Questions relating to how the activity and actions of those surrounding an actor contribute to the actors capability to operate and collaborate effectively.

Awareness could be actor driven (using senses and innate / learned capabilities to process the actions of others and the social context of a space) or technology driven (e.g. a vibrating phone informing the owner of the nearby presence of a friend that they missed), leading to significant complexity in terms of trying to define the interactions that occur, and the behaviours and capabilities required, to arrive at a specified level of awareness.

This returns to a point made earlier: to have awareness the system must provide the capability to become aware, and the user must choose to use this capability, and the result of the interaction of these two factors is a dynamic and varied amount of awareness that is difficult to quantify or control. The variation in a users attention to, and involvement in, another's activity can, however, be formalized in terms of engagement. Pohl & Murray-Smith's focused–casual continuum describes interaction techniques according to the degree to which they allow users to determine how much attention and effort they choose to invest in an interaction i.e. the ability to adapt how engaged they are [175]. In applying this concept to awareness, a user might maintain a casual awareness of another's activity, focusing only when necessary. In the movie browsing example, if a couple is collaboratively searching for a movie to watch together, the casual state could be maintaining a base awareness of what genre of movie a partner is looking at, whilst the user could move to a more focussed state when that genre was of particular interest to them, or when a partner suggests a potential movie to select.

The general concept of awareness has persisted through a variety of iterations and sub-categorisations in CSCW, in part due to this broad definition and applicability, and due to the fundamental reliance on awareness that collaboration has. It is in the definitions of awareness within the work of Gutwin and Greenberg that this thesis will most rely upon. Moreover, this thesis refers to a users involvement and attention to an awareness mechanism in terms of their engagement, and thus their position on the focused–casual continuum.

2.1.3 COMPUTER-SUPPORTED COLLABORATION

Recent work in collocated group interaction has typically been influenced heavily by the devices and technologies that have became available, technologies such as mobile devices, large displays, n–display systems, tabletops, and groupware (systems integrating various devices and platforms for collaboration). Collaboration in collocated groups has predominantly been a business domain problem, namely: how can teams work together more efficiently. Commercial systems like Mezzanine [102] (see Figure 2.2) work in concert with a variety of display devices (be it laptops, tablets, phones, wall-displays etc.) and input devices (tablets, laptops, and phones, as well as pointing equipment, remote controls, etc.) to present a unified space for business activities for multiple users across multiple rooms.

However, such systems are less appropriate outside conferencing environments, given that presentation media available are likely to be fewer, and less predictable. At any one time, there might be multiple smartphones and tablets, but this number might vary significantly. In terms of display surfaces, there is typically only a single, shared TV on the walls, with technologies such as smart wallpaper and tabletop displays still in their infancy in terms of consumer adoption.

Work within the HCI community has tended to focus on feasible ways in which an environment might be co-opted, or augmented to support collaborative interactions. The presence of new display technologies is frequently assumed. For example tabletop interaction lends itself well to this work, given the prevalence of tabletops in living rooms combined with the potential for suitable display technologies to be built-in. The support provided by these displays comes in the form of systems and interaction techniques that provide awareness of activity, and make other's activities accessible to those that are collaborating.

Figure 2.2: Oblong Industries Mezzanine system for collaborative conference rooms [102]

2.1.3.1 SINGLE AND MULTI-DISPLAY GROUPWARE

Given the importance of awareness, there have been a number of studies and systems examining how awareness can be facilitated, thereby improving a small groups ability to collaborate. For example in collaborative web browsing Schmid *et al.* [187] explored multi-device collaborative search where multiple mobile devices could concurrently control one or more web browsers on a physically shared display, whilst CoSearch [5] enabled collocated collaborative web search using a shared PC and multiple mice, showing that this preserved communication and collaboration. In both cases, all users involved had the option of attending to any search activity within the group that was currently on going, essentially meaning that awareness was completely dictated by user engagement.

Such approaches are often termed *Single-Display Groupware* (SDG), meaning that users interact via a single shared display, and are typically collocated and close together. Within SDG, work has centered around shared displays or tabletops facilitating multiple users, for example via multi-touch [152] or partitioning the display to accommodate multiple interfaces or activities whilst avoiding interference. For example, Tse *et al.* [214] found that users would partition this shared workspace themselves to achieve a level of optimality in their collaborative work, whilst You *et al.* [233] used computer vision techniques to detect users and partition and rearrange personal space on a shared display, introducing additional functionality without compromising usability. Bolton *et al.* [22] examined spherical displays, which were found to improve performance in cooperative tasks over flat space with dividers and the ability to "peek" at what was occurring.

Shared displays have been used not just to facilitate digital cooperation, but to aid groups in collaborating more fairly. DiMicco *et al.* [46] presented groups with a shared display detailing speaker-participation rates, and found that the feedback of this knowledge influenced the behaviour of group participants: over-participators lowered the amount they spoke, whilst under-participators increased. Wallace *et al.* [225] found that shared virtual workspaces facilitated decision making, and synchronized group activity via body language and gaze, whilst Lindley *et al.* [124] found that they were as enjoyable as tangible social interactions (in the form of passing photos around), in terms of verbalization/gesture metrics. Bachl *et al.* [9] unified tabletop surfaces with personal displays in the form of tablets, enabling a variety of transfer techniques for moving content from the personal displays to the shared space. Performance was worse with the tablets, but the participants preferred them, and felt forced to collaborate when they did not have them. Indeed, there have even been attempts at creating *ad hoc* shared visual displays from mobile devices, in projects such as "Pass them around" [131], where devices could be tiled/huddled to create one shared display surface, in this case for photo-sharing.

In contrast, *Multi-Display Groupware* (MDG) leverages additional displays to provide elements of task independence, for example supporting personal and shared workspaces [226], shared workspaces and public displays [156] and other such permutations of personal, private, and shared workspaces [208]. Plaue *et al.* [174] demonstrated the benefits of MDG over SDG directly by examining teams completing a sense-making task (trying to understand a dataset to solve a problem) using either a single display, side-by-side dual displays, or opposing dual shared displays. They found that "the location of the second shared display significantly impacted the ability for teams to make logical connections amongst the data. Users were also significantly more satisfied with the collaboration process using the side-by-side dual display condition".

The distinction between SDG and MDG can become blurred in such cases, as the difference between two displays side-by-side versus a large display that is partitioned is largely semantic. However, the fundamental point is that having a shared focal point for activity provides more awareness. Conversely, having multiple personal displays has been shown to offer "sheltered" personalized workspaces with less visual distraction, with the end result of better supporting individual cognition [227].

The LunchTable [156] system exemplified the MDG approach, whilst attempting to retain some of the benefits of having shared focal points, by integrating a multi-touch tabletop display with a large, vertical display for rich information. Manipulation of content tiles, and input mechanisms, were available on the touch display, whilst the vertical display presented this content to the group. Systems such as LunchTable enable those that have access to the tabletop to influence the direction of events. They also share some notable benefits: they encourage physical congruence, the collaborators are forced to share the same visual scope, and have full awareness of what others are doing, and they can inhabit spaces in a non-invasive manner. However, they are not without problems, namely that physical access to the tabletop is required, that the tabletop demands their attention, thus, temporarily at least, drawing it away from anything else, and most notably, for some collaborative tasks, a table is unlikely to be the ideal focal point of a group.

2.1.3.2 MULTI-VIEW DISPLAYS

Some of the problems with LunchTable are common to SDG and MDG approaches. SDG provides a shared focus of attention and thus activity [74], which has been shown to significantly improve users' ability to collaborate [227]. However, having to share a single display is a significant constraint in terms of available workspace and denies users the ability to transition toward more independent or private activity easily. In contrast, MDG allows for task independence and selective or casual awareness. However, this necessitates that there be multiple potential displays to attend to, with awareness managed via gaze transitions between the available displays. Such designs are both costly, requiring many devices, and effortful, requiring interaction techniques be designed to enable efficient use of the available displays and presentational surfaces.

To overcome said problems, one potential approach is to employ multi-view displays. These are capable of providing two or more independent views to one or more users. There are a number of technologies that are capable of achieving this aim [49], which will be discussed in turn.

LENTICULAR DISPLAYS These rely on sheets of lenticular lenses atop a standard LCD screen. Each lenticule directs light from a given subpixel, thus lenticular sheets can be designed to simultaneously direct subsets of subpixels in given directions, allowing for the creation of multiple views based on gaze angle. The design of the lenticules (in terms of width, radius, backing sheet thickness, and orientation) can be adjusted to support the desired number of views, however as the number of views increases, the spatial resolution of those views decreases e.g. [123]. Lenticular displays are forming the basis of the next generation of glasses-free consumer 3DTVs[1] and thus there is a reasonable expectation that displays capable of glasses-free multi-view will become a consumer reality.

PARALLAX-BARRIER OR MASKED DISPLAYS These employ masks, be they singular port-holes [113], or a series of holes or slits [172], to control what subpixels are viewed at a given angle. These masks can be opaque sheets, or dynamic (e.g. liquid crystal sheets as used in

[1] www.tomsguide.com/us/streamtv-glasses-free-3d-works,news-20270.html

MUSTARD [110]), with the properties of the slits/holes determining the number of views, brightness, resolution, and crosstalk[2].

TWISTED NEMATIC LCDS Solutions that do not have additional hardware requirements beyond the initial display have also been developed, for example Kim *et al.* [111] exploited the properties of TN LCD panels (a common LCD panel type) to provide two views based on viewing angle.

ACTIVE-SHUTTER DISPLAYS This solution employs displays with high refresh rates combined with LC (liquid crystal) active shutter glasses to selectively reveal or mask frames as they are displayed. For example, given a display of $\mathrm{X\,Hz}$, and a number of users n desiring independent views, there would typically be X/n frames per user to display said n views. To maintain the effect of motion, these frames would be displayed sequentially $1..n$. If it is assumed $n = 4$ and $X = 240\,\mathrm{Hz}$, then there would be $60\,\mathrm{Hz}$ per user. This would be displayed as follows: first the frame for view $n = 1$ would be displayed (for a duration of approximately $1sec/240 = 4.16ms$) followed by the frame for $n = 2$, $n = 3$, and finally $n = 4$, at which point the process would loop. In this way, each view would have $60\,\mathrm{Hz}$ of apparent motion spread across each second.

To block frames that are not meant to be viewed by a given user, for example being the user assigned to the view $n = 1$ when frames for $n = 2/3/4$ were being displayed, active shutter glasses are used. Their liquid crystal lenses have the capability to block those frames from view by turning from transparent to opaque. For this to be effective, the active shutter glasses must be capable of operating at the same refresh rate as the display, in synchrony such that the correct frames are revealed or hidden as appropriate, typically achieved via IR or RF signalling.

Of the multi-view display technologies discussed, active-shutter displays are the most common and capable currently, with consumer TV's typically utilizing this technology for 3D multi-user stereoscopic views, but also multi-view. For example LG "dual-play"[3] supports two player views for gaming, whilst Samsung "Multi-View" displays[4] and Sony "Simulview"[5] displays support two-player stereoscopic multi-view on the same display for gaming and concurrent 3D media consumption.

Active-shutter displays allow for relatively low amounts of crosstalk whilst retaining high frame rates and image fidelity, albeit at the expense of brightness due to the amount of time

[2]Crosstalk: the extent to which one image is retained into the subsequent image. For example, given a two-view multi-view display, where one view is a car, and the other a boat, crosstalk would be manifested as the boat being visible (ranging from a faint outline to wholly superimposed) in the car view, and vice-versa.

[3]lg.com/us/tv-audio-video/discoverlgtvs/dualplay

[4]samsung.com/us/video/tvs/KN55S9CAFXZA

[5]sony.co.uk/electronics/televisions/x9000b-series/specifications

the glasses are in their "shuttered" state. Crosstalk can be minimized by technologies such as nVidia's LightBoost[6] which can significantly improve brightness and minimize crosstalk through employing backlighting which can be toggled off whilst a frame is being drawn to the display, or display technologies with faster refresh rates and lower pixel persistence[7] such as OLED displays.

Active-shutter displays have some notable disadvantages. They require that users wear glasses (which can potentially be uncomfortable and fatiguing, and dim their view of the world) and there are limitations with respect to the number of views they can feasibly support. While a 480 Hz display that supported 8 independent views (or 4 stereoscopic views) at 60 Hz is technically possible, each frame would last 2.08ms, meaning that each user would view an image for 125ms over the course of every second, and darkness for 875ms. It is conceivable that such a scenario would lead to substantially diminished image brightness, and the potential for eye fatigue. Thus, such displays are likely to be impractical in terms of eventual consumer use. However, they are feasible prototyping platforms for examining multi-view interaction independent of viewing angle for smaller groups, without constraints regarding image fidelity or frame rate. More fundamentally, they offer the possibility of a single TV that can support multiple entirely independent users, of particular relevance to RQ 2.

ADVANTAGES AND DISADVANTAGES Multi-view displays can be used by solitary users or groups, and have a number of advantages over comparable systems in each case, however more-so in multi-user usage. In single-user scenarios they have been used to present different aspects of an interface based on view position, allowing users to move their head to peek at a menu for example [135]. In multi-user contexts, they have been used to support single display privacyware [195], independent and collaborative activity on table-tops, e.g. Permulin by Lissermann *et al.* [125] which supported two users sharing a 1120 Hz two-view display, or Permulin's precursor [3], and independent views in groups such as in the case of C1x6 [120] which employed multiple projectors to achieve a 12-view 360 Hz display allowing for 6 stereoscopic views.

It is in terms of multi-user use that multi-view displays have the most potential. Multi-view displays have the capability for both independent operation and collaboration, with a shared focus of attention throughout. However, unlike in SDG and MDG, transitioning between independent and collaborative states, and gaining mutual awareness of the activity of others (e.g. through glancing, peeking, peripheral vision) must be explicitly designed for, as users no longer have the ability to manage their visual attention via gaze. This is a significant problem with respect to collaboration and coordination, as systems utilizing

[6] geforce.co.uk/hardware/technology/3d-vision/technology
[7] Pixel persistence: the time it takes a pixel to transition from its previous state to its current state

multi-view displays must actively communicate the requisite information to allow users to gain awareness of group activity.

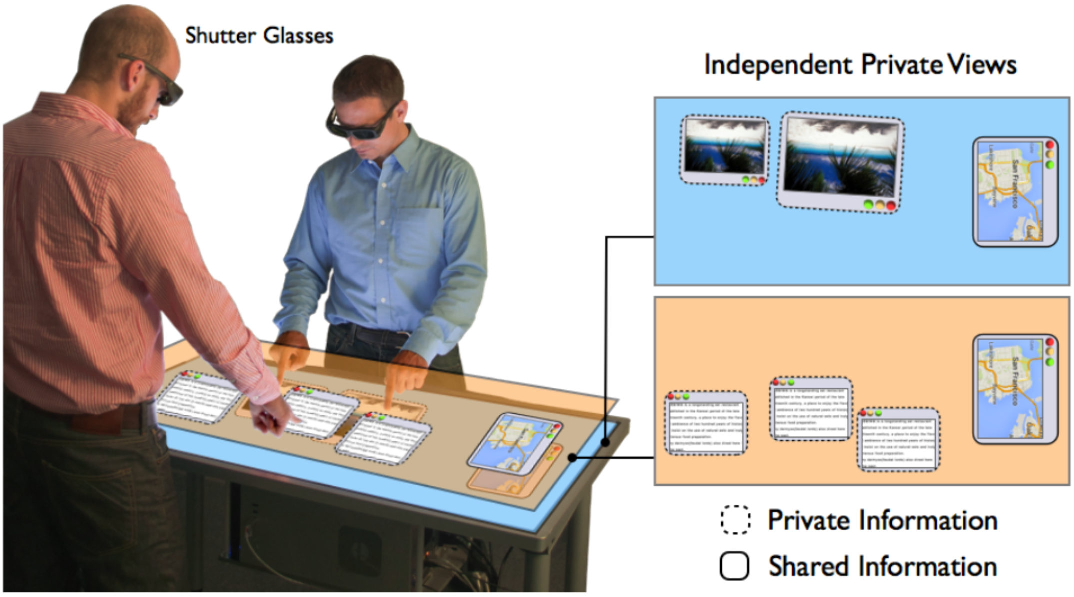


Figure 2.3: Permulin [125] multi-view tabletop, with the ability to provide both independent private views, and shared group views, as well as private information within the shared group views.

Permulin [125, 126] attempted to address this issue by providing a set of behaviours that enabled users to selectively gain a level of awareness of their partner's activity. This was achieved through providing the ability to have both private views, and a shared group view which could contain private information (see Figure 2.3), as well as the ability to peek at a collaborators private view to facilitate activity awareness. They evaluated their system across different collaborative tasks, finding distinctly different usage behaviours across collaborative tasks, with loose coupling featuring more peeking, and tight coupling more sharing, as seen in Table 2.4.

Collaborative Task	Peeking	Sharing
Loose	2.25	4.81
Mixed	1.25	5.62
Tight	1.12	7

Table 2.4: Average number of occurrences of peeking and sharing behaviour across groups for Permulin across collaborative coupling tasks [125].

Permulin both exemplified why multi-view displays have great potential for collaboration, through providing a shared focus workspace with the ability to collaborate or operate independently, whilst also demonstrating the problems faced in trying to provide the capability to transition between shared and private views. However, their display management behaviours were heavily reliant on use of the touch surface table-top display. More generalised behaviours for managing full use of the display, and transitions between available views, would be required if multi-view displays were to be usable in shared TV contexts.

Multi-view displays also bring with them an inherent problem regarding audio sources: given the ability to have n independent views, there is also the possibility of having n independent audio streams, however these audio streams may not have the benefit of being filtered out such that only the relevant audio stream for a view is heard when attending to only that view. As such, there are issues regarding how these audio streams are managed. In consumer multi-view displays, this is typically accomplished by using headphones built in to the active-shutter glasses, however this has notable downsides when considering the social aspect of TV usage: if you are unable to hear others in your vicinity, you are unlikely to be able to interact with them adequately. Alternatively, relying on speakers associated with the multi-view display leads to issues regarding which audio stream should be played back, or whether they should be interleaved, spatially separated and so on.

2.1.4 COMPUTER-SUPPORTED SHARING AND MEDIATED INTERACTION

Whilst MDG, SDG and multi-view displays can all support concurrent interaction, interaction can also be mediated, and interfaces shared. Sharing and collaboration are often linked. For example, you might share access or control of a resource to collaborate. However, unlike in collaboration, in sharing use or control of a system users might have different end goals. Moreover, implicit in the word sharing are its potential antonyms, like "withhold", "keep", or "monopolize" – a user can choose not to share, or share conditionally. The act of sharing can have a quantity (lending control only for a time, or allowing only a subset of control), or can be denied entirely.

Of particular interest in multi-user systems is the sharing of control. Early work regarding how control of systems could be shared between users focused on solutions similar to the groupware of today, in that they would attempt to share control of a system designed for one user at a time (in essence facilitating collaboration). In 1990, Greenberg *et al.* [71] demonstrated a means of sharing single-user applications through view-sharing and turn-taking. It would be easy to dismiss this concept as a relic, given the sophistication of software systems today, but take the work of Abe *et al.* [1] published in 2010, entitled "Tolerant Sharing of a Single-user Application Among Multiple Users in Collaborative Work". This is fundamentally the same concept, still in research two decades on. Why?

The idea of adapting single-user systems represents a pragmatic approach, one that is often deployed due to some constraint preventing the redesign of the underlying single-user system. Perhaps it is a wish to retain the mental model and learned behaviours users have developed, or an acknowledgement that systems designed today are still fundamentally targeted at the single-user model, even though there will be use cases where facilitating use by multiple users (be it concurrent or sequential) are likely to arise.

Ideally, however, systems would be designed from the ground up to be shared, like the previously mentioned “Pass them around”. Another example of such a system would be xShare [127], designed to support sharing control of mobile phones; given the use case where a phone might be lent to a friend or family member for some transient purpose, xShare proposed the means toward limiting the capabilities of the device to match the reason it was being shared; sharing, but on the sharers terms, exposing only a subset of functionality.

Sharing does not have to be pro-active; you might not choose to share, so much as relinquish a resource, or provide an opportunity for a resource to be taken. “Taking as an act of sharing” [142] did just that, devising a scheme where users could place images in virtual folders on their mobile devices, and other users could then attempt to take ownership of these images, giving them the ability to then delete them, keep them, or give them to others. The results of this were that this improved awareness and connectedness to others; these acts are humanising and easy to relate to, and the ways in which the use of this scheme was appropriated were not negative, but positive interactions, playful and jovial.

Sharing does not have to be enacted by users; a system or resource might also be shared based on a predefined ruleset. Ballendat *et al.* [11] developed a system whereby a large vertical display enabled media related tasks (browsing, viewing), adapting the presentation based on the angle and proximity of the user, and pausing when the user was no longer engaged with the system. In this scheme, the user closest to the system was considered most engaged with it, thus essentially sharing the system through a hierarchy of proximity.

Identity is another oft-utilized means of sharing a system or resource; Microsoft’s Xbox One [145] features the ability to discern identity based on voice or facial features, thus allowing for a variety of hierarchical systems to be implemented as a means to share use of systems. Identity can be used to facilitate sharing spaces too; ARIEL [107] featured room localization based on fingerprint tracking and Wi-Fi usage, to better facilitate sharing large, complex spaces, whilst Kray *et al.* [118] featured shared doorplate displays in a residential complex whose resident-centric presentations could be relinquished temporarily based on the needs of nomadic users requiring direction.

As previously discussed, Pohl *et al.* [175] proposed that interaction could be defined by the extent to which the user was engaged in a task. They suggested that there was a set of scenarios where casual interaction might be better suited for a given task, and that determining this level of engagement (and thus which form of interaction, casual or focused / engaged) be up to the user. The system would then adapt depending on how much attention and effort the user chose to invest. They too discussed proximity, pointing to the fact that the bandwidth of user interactions decreases proportional to distance to the device with which the user is interacting, thus mapping engagement to proximity. However, these approaches may not be appropriate for collocated groups in shared spaces interacting with media systems. For example, the proxemic approach does not take into account the fact that proximity to a media system is dictated not by engagement, but by seating arrangement, meaning it might be just as likely to be fully engaged in the system, without being the closest person to said system, as being entirely disengaged from the system at close proximity, given the variety of seating arrangements in living spaces.

In contrast, approaches have been undertaken to design "seamless" interaction techniques, such that, regardless of proxmity, the same mechanics for interaction would be retained. Clark *et al.* [37] suggested a proximity-based interface that allowed users to interact with a media system both within range of touch, and at a distance, transitioning to pointing or device input when far away. Of note here was the fact that in the evaluation of this system, the proximity-based interaction was not frequently used; additionally, having the interface change depending on distance via zooming was found to be counter-intuitive.

This raises some important questions regarding whether an interface should be adaptive within the domain of the living-room. In the case of proximity for example, is there enough space typically available such that the interface becomes unusable at a distance and thus needs to adapt? Moreover, proximity is in all likelihood rendered irrelevant in static seated contexts, whilst attentional interfaces are muddled by the fact that many users may be attending to the display, and all may intend to interact with it at some point. Adapting to attention or seniority is also possible, but fraught with difficulty. If a group of users is currently attending to the display, with one user browsing through available media, to whom should the display be targeted? Moreover, if a user looks away from the screen, perhaps to talk to someone, it could be argued that this does not give sufficient justification that they might want their media paused.

Mortensen *et al.* [153] examined a TV whose viewing angle could physically change on the basis of who was in the room. In a controlled study they found that participants with high status, for whom the TV would prioritize viewing angle, significantly evaluated the TV as being "polite, attentive, and wanting to be used", whilst participants with low status perceived the TV as being the opposite. In this way, simple adaptations have both the capability to enhance viewing, but also alienate viewers if performed unsatisfactorily. Such adaptations might also have social and cultural implications, contradicting or reinforcing societal norms (e.g. undermining the control of the head of the household) or cultural norms (e.g. a particular gesture set being inappropriate) to the benefit of some, and annoyance of others. As such there remain significant unknowns regarding how such techniques can be applied to group interaction with media systems across the variety of contexts that occur in the home.

2.1.5 THE PSYCHOLOGY OF GROUPS

Whilst computers can exert great influence on how a group collaborates, the makeup of the group itself is also a significant component to be considered. This section will discuss various psychological concepts in group dynamics. The basis of this discussion is primarily built upon the work of Forsyth [59] in summarizing decades of research into the behaviour and operation of groups, however where possible the underlying references (or, in the case of out of publication work, recent summaries) are provided.

2.1.5.1 WHAT IS A GROUP?

The definition of a group is commonly considered to be "two or more individuals who are connected by and within social relationships" [59]. Within this definition, there are various subsets e.g. dyads (2 people), triads (3 people), crowds (n people, where n is a large and unruly number), etc. Additionally, the social relationships that form these groups may vary in terms of strength, longevity or reciprocity.

These groups can be categorised in a variety of overlapping manners e.g. planned, emergent, task based (brought about by employment or a goal focus), founded (planned by individuals who remain in the group) etc. The categorisation most pertinent for this thesis is that of intimacy groups [122], for example friends, couples and families, brought together by strong social bonds.

2.1.5.2 COHESION

Cohesion refers to the unity of a group, and can be brought about by various factors, from emotional cohesion (a shared hatred for example), task cohesion (sharing some group-wide aim), to social cohesion ("the number and strength of mutual positive attitudes among the members of a group" [129]).

Cohesion is of less importance for the purposes of this thesis than what cohesion brings about in a media consumption context: is cohesion necessary? This is not as straightforward a question as it seems. Cohesive groups have been shown to exhibit improved performance. For example see [154] for a meta-review affirming that cohesion has a small magnitude effect on performance in small groups. In a consumption context, where productivity and performance is not the primary aim, the makeup of a group can be flexible, and engagement can ebb and flow on an individual level. As such consideration must be given to the *entitativity* of a group.

2.1.5.3 ENTITATIVITY

Entitativity [32] is a measure of whether a group is a collective operating together or a collection of individuals operating apart, and it is relevant because of the transient nature of groups consuming media. For example, consider intimacy groups consuming media together. In some cases, groups could be ascribed to having high entitativity (e.g. why they came to watch content together in the first place) whilst in others they could be described as having low entitativity (e.g. when having distinct individual experiences that can be occurring in a group, like second screening on a tablet whilst simultaneously but inattentively taking part in a group experience).

Entitativity in this context can be seen as a way of describing the collective engagement of the group. When the group exhibits high entitativity, they are engaged in a singular consumption task or activity; when the group exhibits low entitativity, they are behaving as individuals, and consequently will be less engaged with the group. It could be argued that this is a manifestation of individualism versus collectivism: that there are times when an individual might serve his/her own needs over those of the group. However, this is also a failing of the technology being used. In the case of an individual wanting to conduct a second-screen type activity, the mechanisms by which s/he might collaborate with others in the group are limited. Similarly, when control is in the hands of one person, it is easy to imagine others might become disengaged or disenfranchised from the group activity. Thus, the concept of group entitativity, and how this ability to step in and out of belonging to this group entity is facilitated, is of concern to any work looking at group media consumption, in particular RQ 1–4, where technology is intended to intervene to better allow collective operation and thus improve the entitativity of a group.

2.1.5.4 DECISION MAKING & SOCIAL DECISION SCHEMES

Regardless of the entitativity of a group, decisions may still have to be made. Perhaps, in attempting to pick a film to watch for the evening, individuals retreat to their personal devices and collections to browse individually, or perhaps they share the view and control of browsing one media library. The problem remains the same: how can they effectively make a decision?

Decision making schemes are necessary because fundamentally "individuals hedonistically strive to maximize their rewards and minimize their costs" [209, 59]. Thus there needs to be a mechanism by which the outcome of a decision can favour the overall group, and not necessarily one individual in that group (although this may well often be the case in some schemes). Social decision schemes [42, 202] are the mechanism by which the individual's preferences are combined into a single group decision. There are a variety of schemes that can be described as being social decision schemes, and they broadly come under the following categories:

Delegating decisions Individual or sub-group makes decision for entire group e.g. authority scheme/dictatorship, oligarchy, expert answer.

Averaging Combine individual preferences into some statisticized decision (e.g. everyone specifying a genre preference, and a best-match being selected)

Plurality Members vote on decisions, with a majority required before a decision can be taken, or ranking with differing points assigned to options (e.g. Borda count[8])

Consensus Require a unanimous decision, often through iterative implementation of other schemes (like voting)

Random choice Be it the roll of the dice, or a blindfolded selection, etc.

These schemes have a variety of benefits and disadvantages which influence where and when they might be effective. Delegating decisions, whilst efficient, may not be representative of the group as a whole, the result of which may be leaving individuals to feel excluded from the decision making process.

Averaging decisions might lead to group members cancelling each other out leading to an ill-fitting compromise. Plurality has been shown to consistently be one of the best schemes in terms of the eventual decision made, and the time/effort it took to arrive at said decision [90], however there are various issues regarding internal politics, reactions to defeat, behaviour when the vote is close, and even simple matter of arriving at a majority/how stalemates are dealt with.

Consensus schemes exhibit high satisfaction from those involved, however they fall into similar traps as plurality schemes, with politics, pressure to conform, stalemates, and a high cost in terms of effort to arrive at said consensus.

Random choice, perversely, might well be seen as the most favourable scheme in some ways: there can be dissatisfaction with the eventual decision, but this dissatisfaction will be limited to the decision and process, and not focussed on the other members of the group. It also features low cost/effort, and takes everyone's opinions into account equally (in that it ignores them).

Decisions can be framed as being task-based too. Steiner's taxonomy of tasks [203] looked at how groups assembled products, defining five tasks types where individual contributions of members could be combined in different ways e.g.:

[8] http://en.wikipedia.org/wiki/Borda_count

Additive Inputs added together

Compensatory Decision made by averaging together individual decisions

Disjunctive Select one solution from the pool of members solutions

Conjunctive All members must contribute

Discretionary Group decides how individual inputs relate to outcome

There is significant overlap with the social decision schemes mentioned previously: these schemes represent underlying, base ways in which these problems can be tackled.

2.1.5.5 Groups Gone Wrong: Failures in Decision Making, Inefficiency, Group Think, and Conflict

Regardless of what decision scheme is chosen, there will be problems and dissatisfaction:

> "Informed decision-making comes from a long tradition of guessing and then blaming others for inadequate results" [2]

The decision making process can fail in a variety of ways. For example, indecision can dominate and paralyse groups. Parkinson's law [169] states that "work expands so as to fill the time available for its completion"; given half an hour to decide what film to watch, it is easy to imagine the entire time being taken up by debate. Equally, misunderstandings through faulty listening or limitations in information processing can arise, leading to the wrong decision being taken, and thus the potential for greater dissatisfaction with the process. They may even attempt to avoid the decision making process altogether, through procrastination, or satisficing (both satisfying, and sufficing: accepting a low-cost decision as opposed to the best one for the group).

Groups can also be inefficient: the Ringelmann effect [117] identified group inefficiency as stemming from loss of motivation, and coordination problems, stating that groups become increasingly inefficient as more people are added to them. The phenomenon of social loafing compounds this: when an individuals contributions are unidentifiable, then presence of others increases the likelihood of "slacking off".

Groups can also fall into traps: the Abilene paradox [88] (also known as pluralistic ignorance) is a scenario whereby a group takes a decision that is contrary to any of the individuals preferences within the group. This happens through miscommunication such that each member believes their own preferences are contrary to the groups, and thus do not object to the decision made, leading to the entrapment of the group.

Groups can even engage in a process known as "Groupthink" [31, 55, 56], whereby members attempt to minimize conflict and reach consensus without properly evaluating and considering the evidence, all possible solutions/viewpoints, or outside influences, essentially coming to a solution in isolation.

Whilst some of these mechanisms for error may not be relevant to media consumption contexts, it is important to understand the variability by which the decision making process can be co-opted and perverted. And in some, there are pertinent lessons: the Ringelmann effect for example is likely to be a pressure point for the design of any media system which facilitates group usage. If concurrent use of a media system is facilitated, is this opening the door to inefficiency and coordination problems?

In addition, intrinsic to the process of decision making is that of conflict, and conflict resolution. Intragroup conflict can be a result of competition, personal conflict, perceived fairness of a result, perceived procedural justice, perceived distributional justice, lack of communication etc. The sources of conflict are many, however the mechanisms by which they can be resolved can broadly be summed up in terms of:

Avoidance Inputs added together

Yielding Decision made by averaging together individual decisions

Fighting Select one solution from the pool of members solutions

Cooperating All members must contribute

Of these, of most relevance to this work is that of cooperation, of which the primary component is negotiation, which itself can be described in two ways: distributive negotiation, and integrative negotiation. Distributive negotiation refers to concessions and compromise until a middle-ground is reached, whilst integrative negotiation looks for solutions that suit both sides.

2.1.5.6 CONTEXT AND SPACE

For an intimacy group to be intimate, the context it inhabits must be suitable. The equilibrium model of communication suggested that "personal space, body orientation, and eye contact define the level of intimacy of any interaction" [59] (see [10] for an overview), with adjustments to verbal/nonverbal behaviour used to moderate how intimate a given interaction is. Hall [82] suggested that there were interpersonal zones which mediated how intimate a given interaction might be. He defined these zones as seen in Figure 2.4.

It is reasonable to suppose that if intimacy groups are to be examined, considerations must be made regarding both the activities they perform (for example gestures encroaching on

Zone	Distance	Characteristics	Typical Activities
Intimate	Touching to 18 inches	Sensory information concerning the other is detailed and diverse; stimulus person dominates perceptual field	Sex, hugging, massage, comforting, jostling, handshakes, slow dancing
Personal	18 inches to 4 feet	Other person can be touched if desired; gaze can be directed away from the other person with ease	Conversations, discussion, car travel, viewing performances, watching television
Social	4 feet to 12 feet	Visual inputs begin to dominate other senses; voice levels are normal; appropriate distance for many informal social gatherings	Dining, meeting with business colleagues, interacting with a receptionist
Public	12 feet or more	All sensory inputs are beginning to become less effective; voices may require amplification; facial expressions unclear	Lectures, addresses, plays, dance recitals
Remote	Different locations	Primarily verbal inputs; facial and other behavioral and nonverbal cues unavailable	Electronic discussions, conference calls, telephone voice mail, e-mail, online gaming communities

Figure 2.4: Types of social activities that occur in each interpersonal zone, from [59].

interpersonal zones) and the space they are evaluated within. Indeed, even something as innocuous as seating arrangement must be considered if a space is to be deemed suitable. Sommer [198] defined sociopetal and sociofugal spaces. Sociopetal spaces facilitated greater eye contact and verbal communication, whilst sociofugal spaces discouraged these intimate interactions. For example, a group seated round a small table would be deemed a sociopetal space, whilst a group situated on a row of seats bolted to the ground would be deemed sociofugal, and not condusive to the workings of an intimacy group.

2.1.6 SUMMARY OF COLLOCATED COLLABORATION AND SHARING

In supporting collaboration, firstly consideration must be given to the makeup of the group collaborating. For the purposes of this thesis, small intimacy groups (meaning friends, family, and colleagues) in sociopetal spaces that approximate the living room best represent the kinds of groupings that occur in living rooms.

Secondly, the collaborative task must be considered. It must be ecologically valid, and representative of the kinds of tasks that have been observed being conducted. For example, shopping, holiday browsing, and movie browsing are all suitable, loosely-coupled collaborative tasks that occur in the home.

Thirdly, the topology and technologies of available displays must be considered. Incorporating multiple displays and devices can benefit independence at the sacrifice of awareness, whilst relying on a single shared display can be restrictive to individual use. However, technologies such as multi-view displays offer the possibility of combining the best of SDG and MDG.

Fourthly, the interaction with these displays and devices, and their associated interfaces, must be considered. Is it enough to share a single display designed to accomodate concurrent or mediated use? How can the activities of multiple users be made more accessible through available shared displays? And how can interfaces be designed for multi-view displays that offer a viable alternative to such systems? Examining the opportunities in this design space regarding shared use TV displays is the subject of the next section.

2.2 THE ROLE OF THE TV

2.2.1 WHO DO PEOPLE WATCH TV WITH, AND WHY?

The TV is a central component of home life: in the UK alone there are ~52.2 million [165] TVs, equating to 2.34s TVs per home on average [217]. The TV offers a large, high-resolution, gaze-accessible and immersive view of media content, and is often found in both shared social spaces (e.g. the living room) and private spaces (e.g. the bedroom). Of interest to this thesis is the former: TVs which inhabit shared social spaces, often used or attended to by more than one person, as it is these displays that have the ability to significantly affect users' capabilities to interact with, be aware of, and collaborate with each other.

The social groups that utilize these displays tend to be intimacy groups, meaning family and friends. A study by Thinkbox [211] (based on BARB data[9] for 5100 homes, $n \approx 11500$) found that "52% of our live viewing (including single households) is shared, and time-shifted viewing is even higher at 56%", with "most shared viewing [conducted] with one other person". A report by Ofcom [165] suggested that "people are still coming together to watch TV in the living room - 91% of UK adults view TV on the main set each week, up from 88% in 2002" (also based on BARB data). Indeed, this report emphasized the importance of the living-room TV by stating that people were "increasingly reverting to having just one TV in their household - 41% of households in 2012 compared to 35% in 2002", with only 52% 5-15 year olds having a TV in their bedroom, compared to 69% in 2007.

The living-room TV is an important part of homes, with 63% of users polled by Thinkbox [212] ($n = 802$) stating that the television is central to their relationship with the living-room. Why are people drawn toward using the shared living room TV? Whilst there are likely a number of contributing factors to this (e.g. availability of set-top box content), two stand out in reviewing consumer TV market research: the quality and size of the display and its social context. With respect to the quality of the display, a 2012 Ofcom report [164] found that:

[9] http://www.barb.co.uk/resources/barb-facts/faq

> "In the past 10 years we have seen the development of widescreen television, HD television, screens getting flatter and very importantly screens are getting bigger... What this is doing is actually bringing people back into the living room and television is taking on a new role as a family experience whereas 10 years ago, in the early 2000s, we were seeing kids, different members of the family watching different television shows in different rooms using different sets." [163].

With respect to the social context, this report found that 52% of the "individualistic" 16-24 year olds watched TV with the purpose of experiencing it with family or friends, whilst 31% watched for "a bit of company" (see Figure 2.5).

Similarly, a study by Deloitte [44] ($n = 4006$, see Figure 2.6) found that for younger age groups, watching TV together was more enjoyable than watching on their own, with approximately 60% of 16-18 year olds and just over half of 19-24 year olds holding this view. Approximately half of 16-44 year olds agreed that "watching TV is a good way of bringing the family together". Indeed, watching TV together is a commonality around the world:

> It may seem dated, but the image of the family clustered around the living-room set is an accurate depiction of how most people watch television in most countries. [sic] People may have strong ideas about what they want to watch, but what they really want to do is watch together. So the great majority of them first see "what is on" – that is, what is being broadcast at that moment. Restricted choice makes it easier to agree on what to watch. If nothing appeals, they move on to the programmes stored in a DVR. On the very rare occasions when they find nothing there, they will look for an on-demand video. [200]

This is of note because it is often readily assumed that younger generations are abandoning TV usage for alternate displays and devices, however this view is not entirely accurate; the TV remains an important social binding agent in households.

2.2.2 PASS THE REMOTE: PROBLEMS WITH SHARING USE OF THE TV

Given this social context of usage, it might be a reasonable expectation that TV designs have been refined to support the multi-user settings they inhabit. However, this is not readily the case, with problems regarding multi-user interaction and the changing role of the TV with respect to both collaborative and personal / private usage.

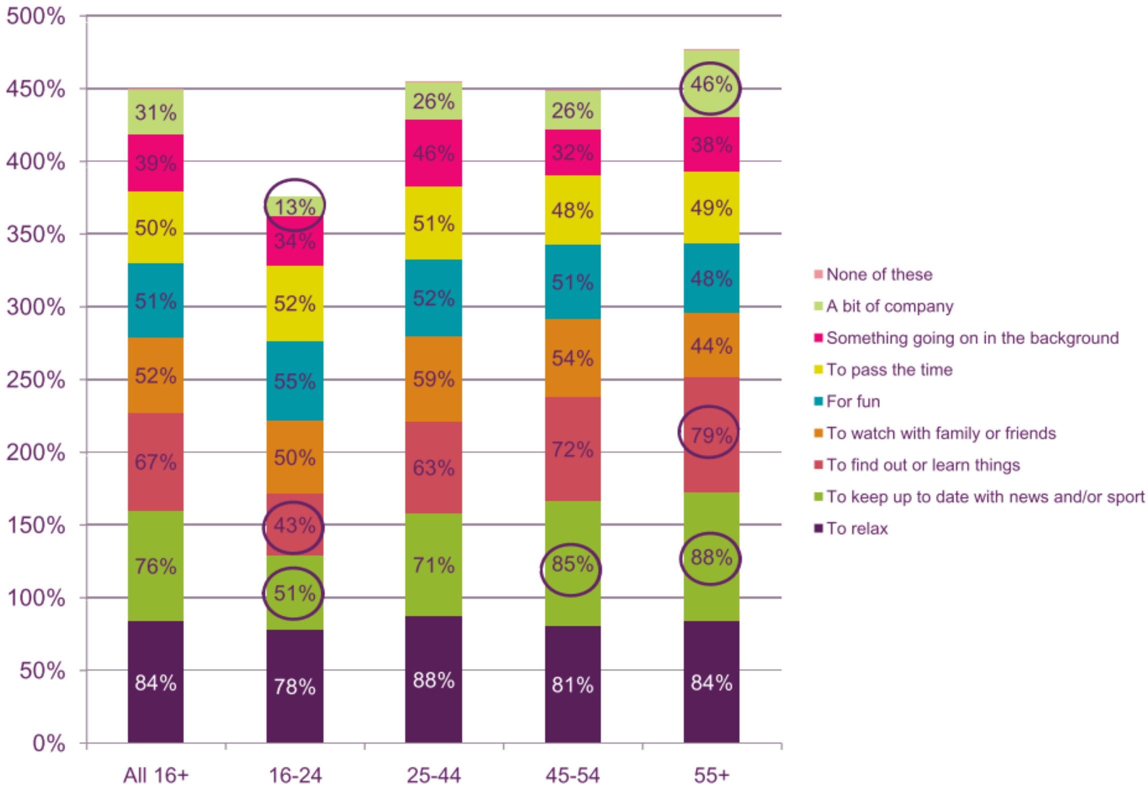


Figure 2.5: Reasons for watching TV, by age group [164].

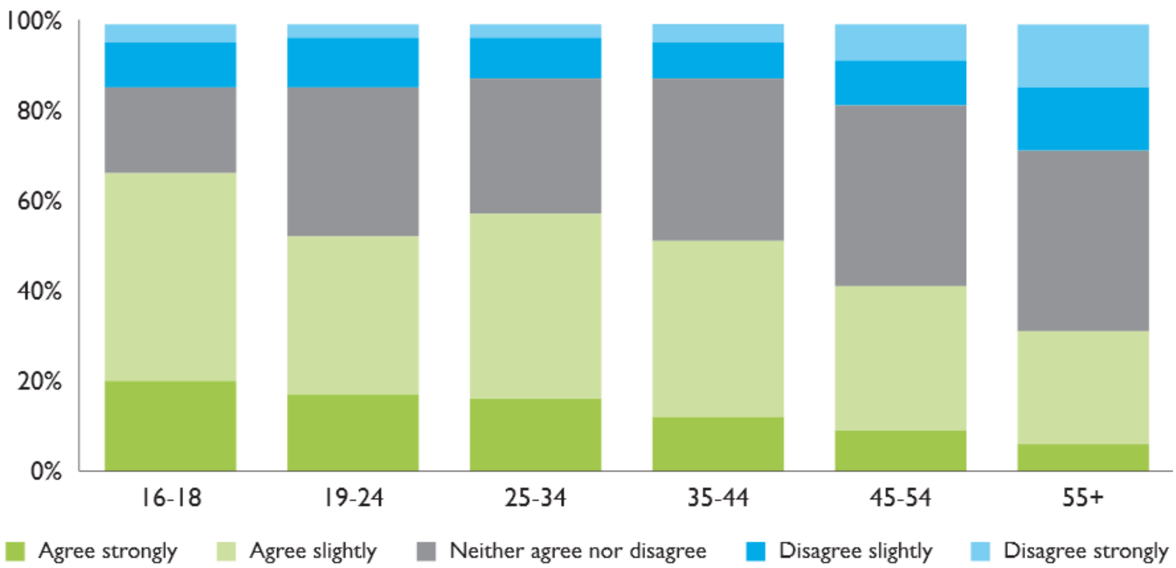


Figure 2.6: Spectrum of agreement with the statement: “Watching TV is a good way of bringing the family together” Deloitte/Gfk [44].

2.2.2.1 MANY INPUTS, ONE DISPLAY

Traditionally, management of the TV was based on social conventions developed over decades of use. Interaction with the TV has iterated upon a single device that is now considered a *de facto* standard: the remote control. It is a device of ubiquity and a universally accepted means of controlling what is displayed. With this ubiquity comes a host of associated management behaviours through which social use can be accommodated: it can be passed, taken, shared, relinquished, hidden, denied.

However, these social conventions are in a process of changing, with new interaction techniques relying on alternate input mechanisms and modalities allowing anyone in the room to exert control. For example, it has become commonplace for modern SmartTVs to bundle multiple remotes (e.g. a standard button remote and a touchpad or gestural remote). Many Smart TVs can also be controlled by apps from any mobile device in the room, whilst consumer TVs (e.g. Samsung Smart TVs[10]), set-top boxes (e.g. the Xbox One[11], and dongles (e.g. Amazon Fire[12]) often provide voice and / or gesture controls. Users have been shown to be receptive to adopting these newly utilized input modalities, depending on situational and application-specific factors [150]. In the case of voice user interfaces (VUIs) consumer adoption of voice activated systems such as Amazon Echo, Apple Siri, and Google Voice search is likely to lead to an increase in both the demand for, and acceptability of, these types of interactions in home settings. In the case of gestural interfaces, a study examining low-energy free-hand gestures for TV tasks [222] found that in some cases gesturing was preferable to remote control usage. It is therefore likely that in some cases these modalities may become the preferred input modality for the TV, with implications for how multi-user use of TV interfaces is facilitated, given the potential for input channels that are open to use by everyone in the room.

In terms of interface design, interaction has typically remained discrete and event based, with some capacity for switching to continuous, pointer-based controls. For example, Samsung Smart TVs feature interfaces designed to support both discrete navigation and pointer-based navigation. whilst Android TV offers a similar capability[13], with both directional-pad and touchpad functions supported. However, in the case of Android TV, the touchpad is used primarily for applications that expect touch or pointer input, with the core TV experience being discrete and grid-based (see Figure 2.7).

[10] www.samsung.com/us/2013-smart-tv/
[11] www.xbox.com/en-US/xbox-one/entertainment
[12] www.amazon.co.uk/Amazon-CL1130-Fire-TV/
[13] www.play.google.com/store/apps/details?id=com.google.android.tv.remote

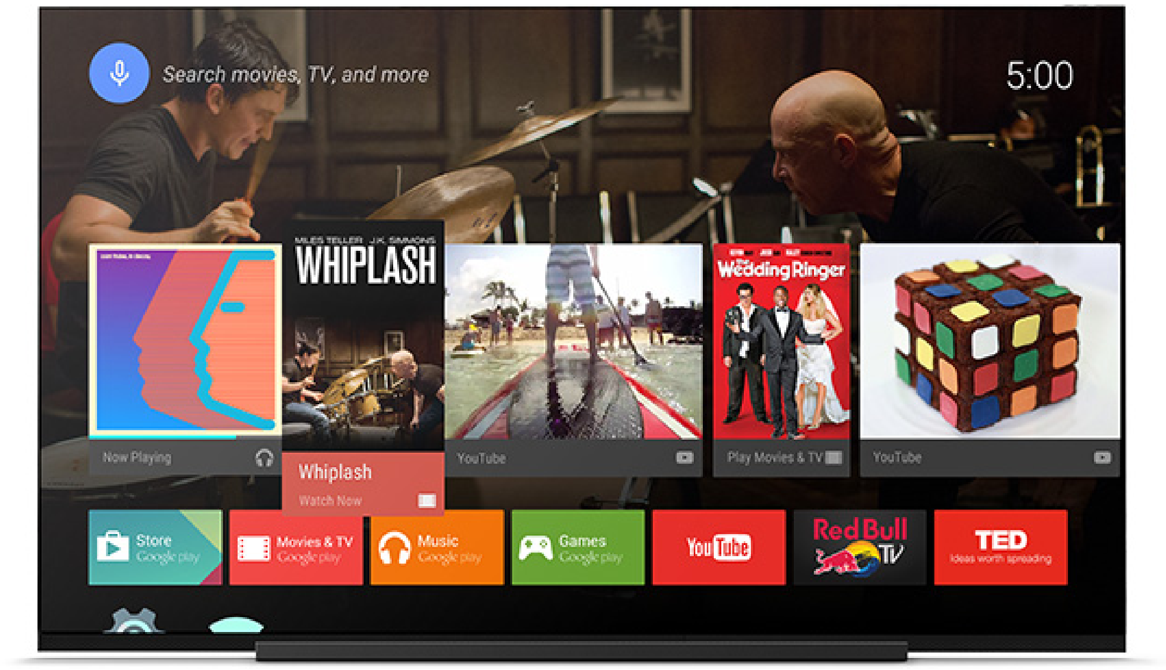


Figure 2.7: Android TV interface, where a grid of options is typically navigated using discrete directional events.

In both cases, facilitating multi-user use is problematic: in discrete systems there is the issue of cursor sharing versus relying on multiple potentially visually distracting cursors. Managing events (e.g. remote control shortcuts, voice commands, gesture commands) also becomes problematic e.g. if a user initiates a transition to another view whilst another user is interacting with some element currently being displayed, what is the appropriate action to prioritise? Whilst some modalities have associated social cues that might help prevent problems of concurrent usage (e.g. voice usage and the acceptability of talking over another user), other modalities and inputs (e.g. gestural controls, remote control, apps) do not naturally have blocking mechanisms. In pointer-based systems, there is additional bandwidth of input, but also significant visual distraction due to the necessity for multiple pointers, whilst continuous input is likely to increase the effort, mental demand, and physical demand required (depending on the input modality and sensing technology in use).

2.2.2.2 Many Activities, One Display

There is also the question as to whether concurrent and shared-use interfaces are sufficient for the variety of activities that multiple users might engage in, and the effect that these activities might have on other users of the TV display. If two or more activities are to be conducted on the TV, e.g. one person viewing live TV whilst the other interacts with an Electronic Programme Guide (EPG), this necessitates dividing the TV display so that each activity has a given region of the display. This screen division is arbitrary and can be designed to suit the content being accommodated. For example, picture-in-picture suits fixed aspect ratio content as there is no unused screen area; similarly a 4-way split of the display, as seen in Samsung multi-link[14] (see Figure 2.8), allows for content designed for the aspect ratio of the display to be scaled down whilst maintaining this aspect ratio.

Figure 2.8: Samsung Multi-link: here the screen can be divided into 4 views, allowing for multiple concurrent and independent activities to be performed, at the expense of sacrificing screen area and increasing visual distraction.

If the aspect ratios of the two activities differ, the screen can be divided in any number of arbitrary ways. For example, in the case of the XBOX One interface the aspect ratio of video content is maintained and an overlay for interactive applications appears on a vertical slice of the display. In this way interactivity is provided, at the expense of a portion of the media being viewed (see Figure 2.9).

Split-screen and picture-in-picture approaches are inherently sub-optimal, compromising use of the display to accommodate multiple activities and users, through either obscuring part of one view to provide another view of poor legibility / size, wasting screen area, or compromising the aspect ratio of the content being consumed. They also offer no privacy considerations; checking email or using a social media application on a TV, whilst feasible with such screen division approaches, is often socially unacceptable to the user conducting the activity, who wants privacy, and to the users forced to give up part of their TV view for this potentially irrelevant activity. Thus, whilst the display can facilitate collaborative activity to an extent, independent activity is problematic and likely to be a distracting addition to the display for other users, whilst private activity is impossible in a multi-user context.

[14] www.samsung.com/global/microsite/tv/uhdtv/mobile/multi_link_screen.html

Figure 2.9: XBox One Snap UI: here applications can be snapped to various parts of the display, with the primary content aspect ratio being maintained but shrunk to use a diminished area of the TV.

2.2.3 THE ROLE OF ADDITIONAL SCREENS AND DEVICES: AUTONOMY AND PRIVACY IN A SHARED SOCIAL SPACE

Personal devices circumvent many of the problems TV displays have in multi-user contexts. They guarantee the user full use of a display that remains private through social conventions but physically shareable if they so choose, a display whose interface they alone control and customize as they see fit. Because these devices are personal, they are invariably connected to personal social media and messaging accounts and offer a semi-private space for conducting activity. However, their usage introduces new problems regarding shareability and social impact.

2.2.3.1 ADOPTION AND USAGE: MULTI-SCREENING BEHAVIOURS

The adoption of these personal devices, and their usage in TV-viewing contexts, is highly indicative of the importance of being able to operate independently and privately. In the UK smartphone adoption reached 61% in 2014 (up 10% since 2013), whilst tablet adoption almost doubled (to 44%) in the past year [166]. This is a global phenomenon e.g. in Australia tablet adoption was 42% in 2014, up 10% from 2013 [162] (based on OzTAM, 3500 homes[15]). These are devices that are widely available and have had a significant impact on the TV-viewing experience, through their use alongside the TV in what is known

[15]http://www.oztam.com.au/AboutOzTAM.aspx

as multi-screening. This refers to usage of a mobile internet-connected device at the same time as television viewing [210], and it is in this way that users attempt to get the best of both worlds in the home: utilizing the TV for immersive, shared entertainment experiences, whilst utilizing smaller displays for personal and private experiences. A report by Google [69] ($n = 1611$) found that:

> "TV no longer commands our undivided attention, with 77% of viewers watching TV with another device in hand. In many cases people search on their devices, inspired by what they see on TV."

This multi-screen usage has typically been categorised into sequential and simultaneous use [69, 148] (see Figure 2.10). Sequential multi-screening (also known as shifting [148] or "quantum" [98] referring to leaps in both time and space) refers to one task or activity being transferred between devices as and when required, e.g. performing a search for an item on a laptop then continuing that search on a tablet later in the day. Of particular note in the context of TV usage, however, is simultaneous usage - that is, usage of more than one screen at the same time.

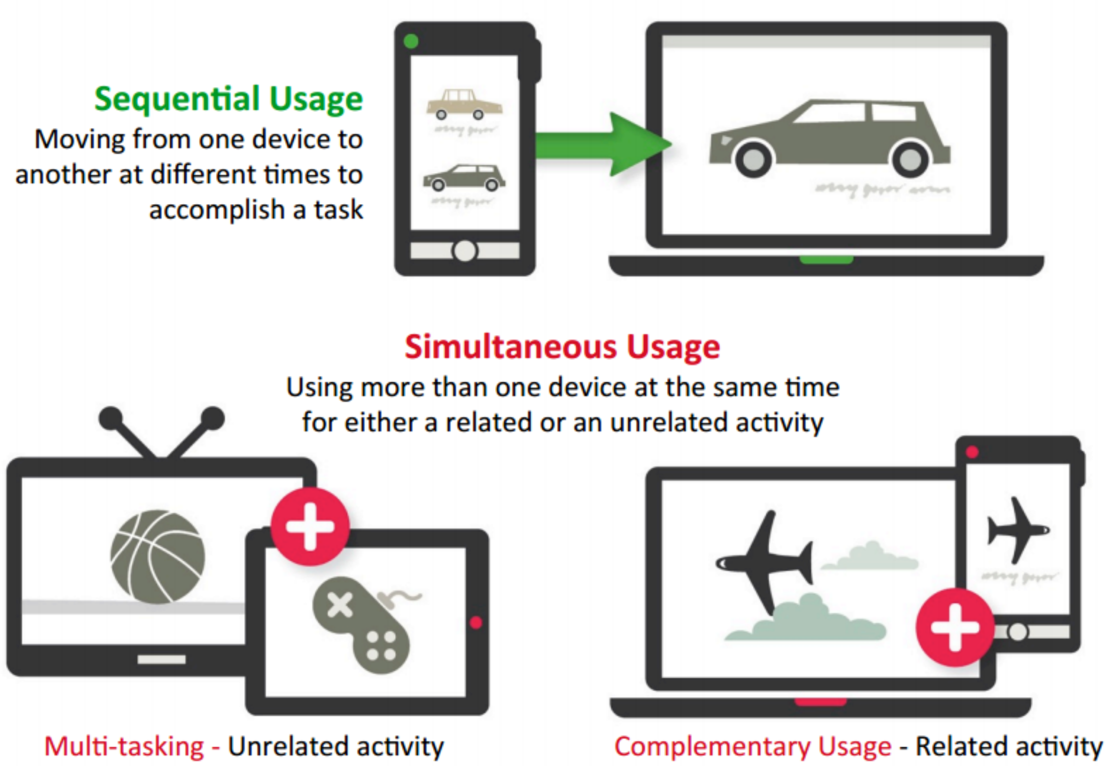


Figure 2.10: A common categorisation of multi-screening behaviour [69].

Estimates vary regarding the extent of simultaneous usage. A report by Millward Brown [148] ($n > 12000$) suggested this constitutes 35% of the time, whilst an Ericsson Consumerlab study [39] ($n = 15000$) stated that 75% of users polled had at some point engaged in multi-screen multi-tasking. This is clearly a highly prevalent behaviour in the home. For example, a Nielsen study of Australian multi-screen usage [103] ($n = 4980$) suggested that 74% of online Australians dual-screened, whilst 26% had triple-screened, most often using laptops / netbooks (63%) smartphones (50%) and tablets (36%). This simultaneous behaviour typically relied on a combination of smartphone and TV displays, with 81% of users polled using this combination every day, whilst 66% used laptops in conjunction with TV. One user remarked that:

> "My phone... I consider it my personal device, my go-to device. It's close to me, if I need that quick, precise feedback" [69]

This simultaneous usage has been broadly categorised in various publications; Microsoft defined different pathways for multi-screen usage such as content grazing, investigative spider-webbing and social spider-webbing [98]. Millward Brown discussed it in terms of meshing (simultaneous use for related content, which was employed 38% of the time that users were engaging in simultaneous usage) and stacking (simultaneous use for unrelated content, employed 61% of the time). Of note here is that this usage is not always driven by the need to engage with interactive media or applications:

> "The online research ... shows nearly one in five men (18 per cent) and over one in ten women (11 per cent) polled have watched two live TV programmes simultaneously within the past year whilst three per cent of respondents said they had watched three programmes at the same time" [39]

Resorting to personal devices for video media consumption instead of relying on the (in some ways) superior shared TV is a common theme in recent multi-screening surveys, and just as prevalent as relying on multi-screening for interactive applications and internet usage. For example, a UK survey by Thinkbox [212] ($n = 802$) found that 56% of the sample had watched TV on screens other than the TV set whilst in the living room, whilst an Australian survey by Nielsen [162] (based on OzTAM, 3500 homes) found that 74% of Australians aged 16 and upwards had watched TV and used the Internet simultaneously - up 14% since 2011.

2.2.3.2 IMPACT ON TV USAGE

The question then is: given the prevalence of multi-screen usage, the variety of multi-screen combinations in use and the vast breadth of user behaviours and activities observed, what effect does this have on the usage of the TV and the ability to socialize and interact in the living room? For a start, multi-screening reinforces use of the TV, with "viewers more likely to stay in front of the TV for longer (64% of multi-screeners viewed for over 15 minutes per time compared to 47% of non multi-screeners)" [210] ($n = 1000$). There is now less of a need to resort to"digital divorce", where couples resorted to going into different rooms so they could watch the TV content of their choosing [161]; any private and personal media activity can be undertaken in this shared public space, at the expense of the ability to potentially use the best display in this space. Indeed one study [213] suggested that "people are planning their evenings around the TV schedule more - the TV is an important social point both within the home and beyond", meaning that multi-screen usage was driving viewers back to shared TV experiences. Indeed in a study of fourteen households, Holz *et al.* [95] found that:

> "1) Participants often joined family members in the TV room to physically be together; when they lack interest in the program, they spend the majority of the show on a secondary device and watch TV only during key moments. 2) Virtually none of participants' app and web use during TV consumption was directly related to the running show." [95]

Device usage is not necessarily a distracting presence; viewers browse the internet as much as they talk to other people in the room [44] ($n = 4006$) (70% frequently or occasionally browsing versus 80% frequently or occasionally talking to others in the room); distracted viewing is the norm. Moreover, second-screening activities such as the use of companion applications or social media (such as Twitter hashtags) accompanying TV content have become a regular occurrence. However, device usage can impact enjoyment and focus of attention: in a UK survey two-thirds of respondents agreed with the statement "If I am really enjoying a programme, I don't really want to use another device at the same time" [44].

2.2.3.3 INTERACTIONS BETWEEN TV AND ADDITIONAL DEVICES: SOCIAL SHARING AND TRANSITIONS

Whilst device usage has played a significant part in enabling independent and private activity in the living room, there have also been a number of consumer technologies that have attempted to open the TV up to these devices, allowing for an element of shareability through the TV. Screen-mirroring (also known as screen sharing, casting, annexing) technologies such as Apple Airplay[16] or Miracast[17] are available in most new mobile devices, allowing the mirroring of screen content via a dongle in the TV, as well as driving entirely separate presentations, expanding the capability of users to share both presentational and interactive content (e.g. sharing mirrored device activity during VMC [199]).

Similarly, playlisting technologies have been incorporated into TV displays, most notable of which is the "casting" capability integrated into Google Chromecast TV[18] dongles (as

[16] www.apple.com/airplay/
[17] www.wi-fi.org/wi-fi-certified-miracast
[18] www.google.co.uk/chrome/devices/chromecast

seen in Figure 2.11). These devices, along with appropriate software integration on multi-screen devices, allow for shared presentational use of the TV through the playlisting of video streams, as well as limited mirroring capability much like Miracast. At a higher level, these shareable actions can be considered mechanisms by which content or activity transitions can occur; this sequential or shifted use of different displays allows for users to migrate the content being consumed or interacted with onto the most appropriate display available, for example moving a mobile gaming experience onto the TV to continue playing with the best display in the room. This was discussed by Cesar *et al.* [35] in their formulation of the uses of the secondary screen: from controlling the TV experience, to enriching said experience (e.g. adding in personalized commentary) and sharing this through the TV, to transferring activity between the available displays. An example of this is in the proposal by Buchner *et al.* for interaction techniques for collaborative TV, whereby they envisaged that content could transition between devices and the TV seamlessly [27].

Figure 2.11: Example of social sharing using the Google Chromecast dongle and associated smart device apps. Here a media experience is controlled by both a phone and a tablet, with the Chromecast-enabled TV having the ability to stream media directly from the internet, or from a given device.

Indeed there is significant scope for inferring this appropriation (or "cyber-foraging" [38]) of available displays. However, the acceptability of interactions such as these is likely tied to the social makeup of the group using the TV e.g. is it acceptable for a relative outsider to the household to appropriate the TV for sharing content? Devices like Google Chromecast offer guest modes specifically designed to allow for such use cases, whereby proximate users not connected to the household network can still interact with the TV (e.g. sharing video, photos etc.) with no restrictions. As yet the extent to which variations in the familiarity / social makeup of a group might effect willingness to appropriate the TV is unknown, nor whether the TV should be made as accessible as this e.g. is proximity / geo-fencing sufficient to allow multi-screen devices access to the TV[19]?

2.2.3.4 PROBLEMS WITH MULTI-SCREENING

Given the adoption and usage of multi-screen devices, it is reasonable to assume that multi-screening fulfils the majority of user needs: the living room TV remains a shared social focal point with one common media experience, whilst independent and collaborative activity is offloaded to individual personal devices of varying capabilities and sizes. However, supposing that everyone in the room has access to alternate displays to the TV (which will not always be the case), this usage presents two problems. Firstly that users are together, but alone, ensconced in their own private media experiences, and secondly that users are having to resort to smaller, less immersive displays whose content is not readily accessible to others. Whilst there is a capacity for explicitly sharing content using devices, shared-use interactive content and casual awareness of non-private activity are greatly impeded. The result of this is that users are potentially cut off from a significant portion of the experiences and activities of others around them.

CASUAL AWARENESS & SHAREABILITY: TOGETHER ALONE The private "digital bubble" [119] of device usage has long been discussed as raising a problematic barrier to socialization and interaction, with mobile phone use in particular having significant anti-social connotations [216] and encouraging "digital narcissism" [180]. Rogers suggested that technology should encourage users to "be more creative, playful and thoughtful of each other and our surrounding environments" [180].

Efforts have been made to burst this bubble. "There's Not an App For That" [179] suggested that technology and applications should aid users in breaking from closed-off, heads down interactions into "confront<ing> the world", for example encouraging heads-up and face-on interactions. This exemplified mindful interaction, which was "about being very close to people; in their 'now', even when physically apart" [179]. An example of this is in the proposal of Lucero *et al.* [132] regarding mobile collocated interactions, whereby users would "take an offline break together", pooling their device resources toward "shared multi-user experiences". They aimed to facilitate joint attention, whilst enforcing a break from

[19] Victims of the Chromecast "RickMote" controller might suggest not: wired.com/2014/07/rickroll-innocent-televisions-with-this-google-chromecast-hack

online socialization, appropriating mobile device displays to pass photos around a table. This emphasis on shareability and joint attention is important as it underlines how collocated interactions are made to be more effective, through the ability to share awareness, and take part in shared activities.

However, mobile devices may not be the most shareable displays in the room. Terrenghi *et al.* [208] discussed scale of displays relative to users' visual angle and distance, noting that the scale of the display must match the social interaction space. In using multi-screen devices, users erect barriers to socialization, and their ability to be casually aware of, and perhaps join in with, the activity of others is impeded.

These barriers have been reduced by technologies such as Miracast and Chromecast, however these approaches are sub-optimal. The adoption and usage of Miracast and other screen mirroring technologies is low. An NPD survey [76] ($n = 2600$) of smartphone users found a 40% awareness of the existence of screen-mirroring capabilities, with only 7% having ever used such features. Of these individuals, 75% had used this capability for mirroring videos, whilst approximately 50% had mirrored photos. The study stated that:

> "Bringing sharing experiences to a larger consumer base will require simplifying hardware requirements [and] amplifying the value of being able to share content across screens"

Although screen sharing is a low-cost way of sharing content between multiple users, it also has some notable limitations. In mirroring screen content, elements of the device interface that are not relevant, or not being attended to, may also be shared. Additionally, screen-mirroring restricts the ability for multiple users to concurrently interact, as it is essentially multi-screen single-interface groupware. It is feasible that these reasons have contributed to the lack of adoption, with little facility for multi-user interaction provided. As such there remains user activity that is isolated on devices with no technological facilities for casual awareness. Sharing must be explicitly managed regardless of if the activity needs to be private or not, and no more than one device or piece of media can be shared at a time.

SIZE & IMMERSION When consumers watch a TV programme or movie on a TV, they do so because the TV offers the most immersive and shareable experience: the TV is the largest display in the room, often has additional capabilities for improving immersion (e.g. 3D rendering), is accessible from a variety of gaze-angles, and presents a shared audio experience often employing positional audio. Indeed, larger displays have been shown to increase immersion, with a study by Hou *et al.* [97] finding that large displays resulted in a greater sense of self-presence than smaller displays. A user choosing to instead watch live TV on an alternate device such as a tablet or phone is inherently sacrificing many of the benefits of larger displays to be able to indulge in a personal media experience other than the one currently presented on the TV. This is a trade-off that is inherently less than ideal. If a TV and its associated audio system had the capability to allow for multiple independent viewers, would the 56% of users that were found to have watched TV on screens other than the TV set whilst in the living room still resort to this behaviour? While there would be justifications for this (for example if content were inappropriate or private), it is reasonable to assume that shared utilization of the TV would be preferable if possible.

2.2.4 Summary of Problems In Designing A Multi-User TV

There are a number of ways in which TV media system user interfaces can be designed to accommodate multi-user use, e.g. multi-pointer / cursor interfaces, split-screen / screen division interfaces, or offloading interaction onto other devices or screens. Additionally, there is a need to design for the realities of modern homes where multi-screen usage has become the norm. Although there is potential to significantly expand the capabilities of the TV display, there is a culture of personal device usage which is growing year by year. Each of these approaches has particular problems and trade-offs, as discussed thus far; in designing a multi-user TV there are a number of problems that must be solved:

2.2.4.1 Interaction

The integration of new sensing technologies opens up the capability for new input modalities (such as gesture and voice) and mechanisms (such as using smartphones, wearbles such as smart watches etc.). How can TVs be designed that support interaction from every corner of the room? And to what extent should existing behaviours for managing use of the TV be retained, given they have evolved around the dominant input mechanism of the remote control? For example parents might once have taken the remote control away from a child; how can such behaviours be incorporated to a multi-user display where there is no physical token of control to manage? And should concurrent multi-user interaction be supported, or should control be mediated between users? This forms the basis of RQ 1.

2.2.4.2 Facilitating Collaborative and Independent Activity

The reliance on multi-screening behaviours is fueled in part by limitations in TV display technology: currently, the TV cannot support private independent use. Although screen-division approaches allow for a degree of independence, they increase visual distraction and sacrifice display area and immersion. Similarly, multi-screen approaches sacrifice immersion through the use of smaller displays, and erect isolating barriers between users, with awareness of the activities and experiences of others greatly impeded.

Given that multi-screen usage is now well established, this raises two questions: can the isolating effects of multi-screening be diminished, through providing some form of shared awareness using the shared focal point of the TV display. And can one of the root problems that cause multi-screening, namely that the TV cannot support both shared and private independent activity, and transitions between these states, be solved, perhaps by utilizing display technologies such as multi-view displays? This forms the basis of RQ 2 and RQ 3.

2.2.4.3 MANAGING SHARED AUDIO SPACES

Supporting multiple independent views or content streams necessitates that there be support for multiple associated audio streams to also be consumed. In consumer systems such as the aforementioned Samsung Multi-Link interface, audio focus was managed exclusively by the user; in this case the user would select which quadrant of the screen they wished to listen to, or pair a Bluetooth audio receiver up to the TV to receive audio for one quadrant in particular in the case where users wish to consume separate audio sources.

Where multi-view displays overcome physical constraints regarding viewing, there exist equivalent audio technologies with the capability to provide per-user audio streams. Readily available consumer off-the-shelf (COTS) solutions exist already, for example bone-conductance headphones allow users to receive audio streams without obstructing their capability to hear their environment, albeit at the cost of audio fidelity. However, as with multi-view and active shutter glasses, there are likely to be acceptability issues in requiring users to wear additional peripherals, albeit technologies such as Google Glass may lead to widespread adoption of bone-conductance technology. More generalisable, and wearable-free, solutions for per-user audio do exist within the remit of cutting edge research, for example through directional sound-beams (e.g. BoomRoom [155]), whilst existing COTS 3D audio / surround technology and mobile devices might also be utilized to create shared sound spaces, at the expense of perhaps suffering some amount of audio crosstalk.

2.3 TV DISPLAYS AT-A-DISTANCE

As discussed in the Introduction (Section 1.2) “Sync-watching” [64], or synchronous at-a-distance media consumption, helps users that are geographically separated feel closer to those they watch with [133], and engender greater intimacy [41] in their relationships. The importance of this effect becomes apparent when the scale of one particular demographic is considered, namely couples in long-distance relationships. In the USA alone, there are estimated to be 7 million couples in long-distance relationships, with census data from 2005 suggesting that there are approximately 3.6 million married persons who live apart “for reasons other than marital discord"[20], for example because of economic migration or education. Indeed, as many as 75% of students in the USA are likely to have taken part in a long-distance relationship during their college education [201]. This is a significant portion of the population for whom technology facilitating at-a-distance synchronous media experiences could strengthen their relationships. As such, this section will discuss work within HCI on supporting long distance relationships, before then specifically examining TV at-a-distance.

2.3.1 Technology Supporting Long-Distance Relationships

Effective communication is a fundamental component in maintaining long-distance relationships. Where once, communication channels were limited to letters and phone conversations (see [40] for a summary of pre-computer research into communication channels), computer technology has slowly supplemented and replaced these channels with email, video-mediated communication, low-cost conversations (allowing for calls to be made at any time) instant messaging platforms and social media [41], cumulatively allowing for a level of awareness and connectivity that is both greater and more immediately accessible (e.g. via smartphone technology) that pre-computer. For example, [4] examined how "individuals mindfully use communication technology to enact their relationships" when geographically separated (specifically looking at overseas Filipino workers), through computer-mediated communication, finding that technology made it easier for those at-a-distance to "overcome their aversion to being in long-distance relationships and overseas employment"; in effect, technology provides sufficient support to make such relationships a feasible possibility. However, participants frequently noted that:

> It's really very different when it's face-to-face. Even if I can identify her mood in phone calls, it's not enough. I think intimacy... (involves) seeing the person face-to-face. Technology really cannot capture it.

Neustaedter *et al.* [159] noted that those in long-distance relationships appropriated communication technologies in ways that made sense to them, for example facilitating a sense of shared living (e.g. "connect[ing] two locations in a more permanent fashion") and supporting sexual intimacy.

Given this, the importance of novel ways in which to facilitate communication, and re-create some of the experiences that are denied to those that are at-a-distance, becomes apparent. Technology (and more specifically HCI) has been shown to be able to play a significant role not just in facilitating communication and the transmission of awareness information, but in mediating intimate relationships, even when not necessarily having been designed to fulfil this role:

[20] http://www.longdistancerelationships.net/faqs.htm#How_common_are_long_distance_relationships

> "Most available technologies however focus on the transmission of explicit information, which neglects the emotional and subtle communication so typical for close relationships. This becomes apparent, for example, in interesting (mis-)uses of the telephone. In Italy people engage in a social practice called the squillo. A friend calls another and lets it ring only once to send a little 'I think of you,' a token of affection and act of emotional expressivity rather than an explicit act of verbal communication. However, the telephone itself is not built for this. The squillo is, thus, rather a product of people's inventiveness to fulfill their needs even in the face of 'inappropriate' technological solutions." [89].

Hassenzahl *et al.* [89] reviewed and conceptualized this work in terms of relatedness "i.e., connectedness, intimacy, love, belonging, closeness, or togetherness) in romantic (and other) close relationships beyond explicit verbal communication and simple emoticons", noting multiple strategies for providing this relatedness, namely awareness, expressivity, physicalness, gift giving, joint action and memories.

There exist a variety of recent notable examples of these strategies, the most pertinent of which to this thesis are in the domains of awareness (covered earlier in this literature review), expressivity, physicalness, gift-giving and joint action. In terms of physicalness and expressivity, systems such as YourGloves [67], which enabled the perception of at-a-distance hand holding (see cubble [115] and Feelybean [114] for other examples of haptics at-a-distance), sleepyWhispers [66], which created a synchronous connection through pillows, and Kissenger [184], which allowed for transmission of a kiss between two remotely connected people, have all been demonstrated as having the capability to impact relatedness through re-creating sensations of touch and social presence. However, there are significant overlaps with gift-giving and joint action with each of these approaches, for example a kiss can be given without reciprocation, or could be reciprocated in real-time. Similarly, technology can be designed to explicitly accommodate behaviours such as gift-giving and joint action. For example, Furfur [36] examined a robotic pet which reacted to, and transmitted interactions between, remote users, providing a continual presence and a conduit for joint action and gift-giving through interaction with the pet. These technologies are notable because they emphasize both the broad range of ways by which togetherness can be facilitated, and that the role of technology is not fixed, with emergent behaviours and usage providing valuable insights into how this togetherness was perceived.

2.3.2 TV AT-A-DISTANCE: WHAT IS CONSUMED TOGETHER AT-A-DISTANCE, AND WHY?

The TV, too, can be used as a means of increasing relatedness and togetherness between people. It is a hub for social interaction, and because of this, watching programs suited to discussion, such as news and sports, is commonplace, with some program types shown to engender feelings of community within their viewership [17]. Being geographically separated from partners can impose a significant burden on relationships, curtailing the possibility of these shared experiences. In terms of supporting socialization at-a-distance, one option is to enable asynchronous experiences, thereby negating problems regarding synchronization of content playback across multiple geographically separated parties. For example, CollaboraTV [158] used avatars to provide a virtual audience of synchronous and asynchronous users, with 53% of participants agreeing that the social component made watching TV more engaging and enjoyable. Ducheneaut *et al.* [53] proposed audience silhouettes as a non-disruptive means of conveying the presence of other users, whilst Vatavu [221] built upon this work to provide real-time audience silhouettes, where their presence affected not only users level of enjoyment, but also their own posturing and gesturing. Anonymization also makes such systems suitable to shared viewing with any currently available viewers. On a broader scale, Schirra *et al.* [186] examined the motivations for live-tweeting across a season of *Downton Abbey*, finding that the sense of connectedness such experiences provided was a significant motivating factor.

2.3.3 SOCIAL TV AT-A-DISTANCE

The biggest benefits of social TV are to be had when there is a deeper social link between those viewing the content. Those in relationships, familial relations, and close friends are all groups for whom geographic separation can impose a significant cost in terms of togetherness and intimacy. Consuming TV content with others at-a-distance is one way in which technology can play a significant role in bolstering intimacy [230]. Bernhaupt *et al.* [17] featured interviewees that used video-mediated communication (VMC) for shared viewing of soccer matches and TV-quiz shows, to approximate the experience of "doing something together", with socialization aided by the shared reference point of TV.

For TV at-a-distance, VMC is often purported to be the primary means for communication, due to the intimacy and privacy this medium allows [28]. Neustaedter *et al.* [159] examined how couples communicated at-a-distance, demonstrating that the presence provided by VMC was key in providing intimacy, reinforcing findings from Aguila *et al.* [4] regarding computer-mediated communications easing loneliness and increasing feelings of closeness, and Dainton *et al.* [40] regarding relationship satisfaction. In interviews, seven participants watched television or videos together, using a laptop placed near to, or in front of, a couch such that they could broadcast their reactions. VMC was also used during other parallel activities, e.g. eating dinner, reading, and gaming. The importance of these shared experiences was emphasized by Brubaker *et al.* [25], with one participant describing a period of 4.5 years in which he and his partner used Skype to enact movie date nights to maintain their relationship. In a survey of 24 professionals that relied on VMC in their personal and professional lives, they found that 57% of participants had used VMC to share activities with others, including “attending parties (22%), family events (32%), and watching TV or a movie (26%)”.

Macaranas *et al.* [133] examined the usage of VMC for at-a-distance video consumption in three parts. In a survey (106 respondents), approximately a quarter of respondents had tried sync-watching at least once, with another quarter expressing interest in trying it, with a bias in these responses toward younger age groups. In a field study (56 participants, intimacy pairs), they had participants schedule a time with their remote companion to watch together. 15 minutes prior to watching the program, participants were expected to log in to Skype and initiate a video chat with their partner, with synchronization achieved by starting the video playback at the same time manually. Finally, in a lab study, they examined the effect the viewing location had on the video-mediated communications experience, comparing Local (watching TV in the same room) to Picture-in-Picture (PiP, with their partner inset on the TV), and Proxy (with their partner on separate device) Conditions (see Figure 2.12). The found that PiP was rated the least enjoyable, with no significant differences between Local and Proxy, and it had the lowest Social Presence (SP) score, with Local having significantly higher SP than PiP or Proxy. They concluded that this suggested “the communication media fidelity plays a strong role in the social connection of the experience”. However, the results of the lab study were contradicted by the field study where, given the option of selecting which configuration out of PiP or Proxy to use, 61% of participants opted to use the PiP configuration, with no significant differences between Proxy and PiP found in terms of enjoyment. Moreover, they found that participants experienced a high degree of connectedness in the field study, ascribed to the common ground and shared activity of the video experience.

Macaranas *et al.* suggested that the next step in such work would be to develop software and/or hardware to support watching together remotely, suggesting that there lay challenges in “initiating the experience, choosing the program to watch, closely synchronizing playback, and solving audio crosstalk”. Furthermore, they suggested that “watching TV is but one of

Figure 2.12: The lab study conditions from [133]: (A) watching in the same room; (B) Picture-in-Picture; (C) Proxy (remote person on separate device).

many possible remote shared experiences. This study strongly supports rich media beyond audio communication in remote shared experiences. This is a rich design space that deserves more exploration".

There has been a number of research projects that have investigated these challenges. Harboe *et al.* [85] presented "ambient social TV" where users could see what others were watching and send lightweight messages, whilst Wiesz *et al.* [229] integrated text chat with video viewing successfully. Harboe *et al.* [84] provided an open audio link between participants' homes, finding that social TV "added value over and above watching alone", helping to "relieve boredom and provide distraction during commercial breaks and slow segments of the show" and "enhance the intensity of the experience, such as when two rooms cheered together at an event in the game". Zync [192] was one example of integrating synchronous sharing of video content through an instant messenger program, where users used video as an enhancement to conversations, providing a common background as attention to the conversation varied. Palviainen *et al.* [168] supported presence and togetherness through voice and text based chat, gestures with avatars and a social EPG. There is also the question of how in-sync users need to be. Geerts *et al.* [62] concluded that when using speech chat at-a-distance, users noticed differences above 2 seconds, whilst using text chat delays up to 4 seconds were tolerable. In the consumer realm, aside from multi-player gaming, there have also been attempts at operationalizing synchronous media consumption, for example the former XBox 360 Netflix "Party mode" [157], and sites such as *rabb.it*, *togethertube .com*, *letsgaze.com*, *plug.dj* and *showgoers.tv* all providing varying browser-based means for synchronizing playback of various media across multiple geographically disparate users. Indeed, other forms of media, such as music, may be able to play significant roles in terms of at-a-distance intimacy. Neustaedter *et al.* [159] found that two participants watched music videos together through synchronizing the start of YouTube clips. They noted that "both participants enjoyed seeing their partners' facial reactions to the songs and videos over their Skype connections".

In such forms where there is no anonymity provided, who users consume this media with will likely be limited to their close social connections. For example, in a workshop Hess *et al.* [91] had one participant explicitly request the ability to see what video their friends were watching at the moment. This "triggered off a critical discussion because the participants only want to involve a small subset of their buddy list". This need for a strong social connection between users reflects work by Dezfuli *et al.* [45] who found that close friends and family were those people most wanted to consume such media with. This also has implications for how shared experiences are initiated, with scheduling such events proving difficult for many [4], necessitating the development of routines as to when partners would be available for each other. Technology can play a part here, for example Metcalf *et al.* [143] used ambient lights to draw attention to the TV when others in the social group were watching.

2.3.4 SUMMARY OF TV AT-A-DISTANCE

From the TV at-a-distance literature it becomes apparent that, despite the technological advances in consumer TV technology, there has been no concerted push toward implementing an at-a-distance synchronous social TV system on an existing consumer TV platform. This is a key research challenge because doing so would demonstrate firstly the feasibility of enabling at-a-distance TV experiences for consumers right now. And secondly, it would provide a means by which ecologically valid insights into at-a-distance behaviours and consumption could be provided. This would build upon the lab-based studies that have previously been discussed. Moreover, such an effort could examine the extent to which other forms of media, such as music, might be consumed at-a-distance, and the impact on a relationship this could have. This forms the basis of RQ 4.

2.4 VR HMDs AND MIXED REALITY

The technologies and systems discussed thus far represent only a portion of the transformative living-room technologies with the capability to impact user behaviours in the near future. There are a number of devices and displays likely to supplement or even replace TV usage entirely for some tasks, as presented in Figure 2.13. Here, a devices influence over TV usage is described in terms of a continuum from interaction toward wholesale replacement.

These technologies have the potential to improve how users interact with the TV, augment their usage of the TV, replace their usage for some media types and contexts, or even supplant the TV entirely. The effect of mobile devices on our usage of TV has been previously discussed, with their capability to move along this continuum: they can be conduits for interaction and control, sharing content and activity to the TV, or provide the personal and private experience the TV cannot.

In terms of interaction with the TV, other technologies and form factors are already playing significant roles. Technology's capability to understand other forms of input, for example voice and gestures, has improved significantly. Such inputs are now commonplace in consumer smart TVs (albeit in limited forms with questionable adoption) with significant advancement occurring regarding how gestures are designed and detected (e.g. fine hand gestures targeted toward TV interaction [222]). Wearable devices (e.g. smart watches) will provide new avenues for input to TV systems, increasing the likelihood of concurrent interaction. Interactive surfaces will provide an alternative, gaze accessible, means of sharing activity in groups, circumventing some of the discussed limitations regarding screen-division (e.g. what happens when every wall is a screen, such as in the case of smart wallpaper [33] where the wall augments the TV consumption experience with both relevant content and

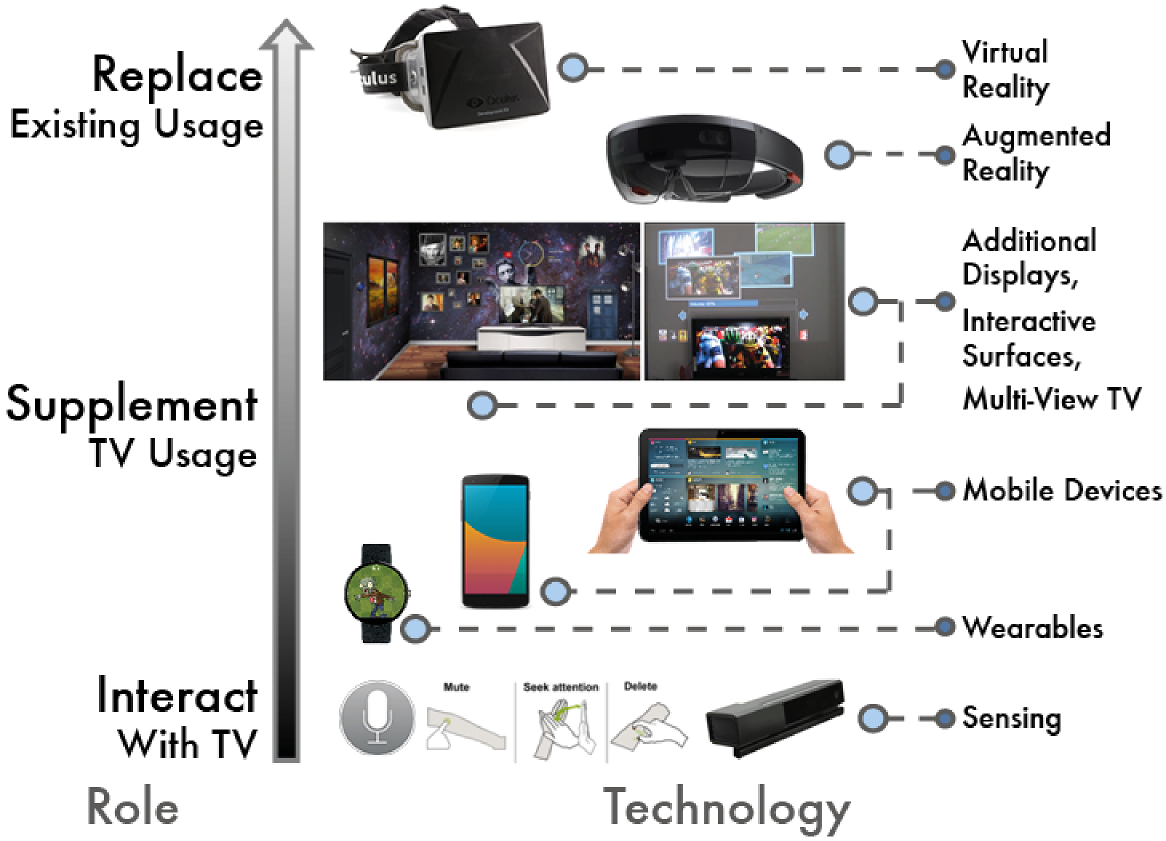


Figure 2.13: An overview of new technologies likely to play a disruptive role in use of the TV. From bottom to top, left to right - **Sensing:** Examples of how interaction with the TV might change, with voice input and gestures (e.g. skin gestures, pictured [228]), as well as an example of existing living-room sensing, the Kinect V2. **Wearables:** Android Wear smartwatch (www.android.com/wear/). **Mobile Devices:** Phone and tablet form factors. **Additional Displays:** Left: Smart wallpaper concept [33] Right: Interactions beyond the physical TV screen [220]. **Eye-wear:** Microsoft Hololens Augmented Reality (AR) head-mounted display (www.microsoft.com/microsoft-hololens/en-us) and Oculus Rift (Virtual Reality) VR head-mounted display (www.oculus.com/).

aesthetics, themed to match a programme being watched, or the space around the TV can be augmented [220]). This in turn could allow for TV interactions to be offloaded onto the surrounding space. Flexible and alternate form factor displays might augment particular contexts and spaces with interactivity that previously could not accommodate standard consumer displays.

2.4.1 Resurgence of VR

Of particular interest are Augmented Reality (AR) and Virtual Reality (VR) head-mounted displays, which may replace the TV entirely in terms of being the most immersive display in the room. Despite significant research and development in the 1990s, the immersive VR experiences envisaged did not reach consumers. [100] posited a number of reasons for this e.g. the technical quality of HMDs was considered poor (in terms of resolution, Field of View (FOV), comfort, motion sickness, etc.), socialization was not facilitated (with users unable to interact with others), the graphical quality of the rendered scenes was poor, and the cost was prohibitive.

However, the Oculus Rift's Kickstarter campaign triggered a resurgence of interest in Virtual Reality Head-Mounted Displays (VR HMDs). Advances in small form factor displays (e.g. the high refresh rate, low persistence, high definition panels typically used in mobile devices) demonstrated that high fidelity VR HMDs were now not only technologically feasible, but a viable and affordable consumer reality. What followed has seen the likes of Samsung (Gear VR), Sony (Morpheus / Playstation VR), HTC / Valve (Vive), Oculus / Facebook (DK1/2, CV1) and Google (Cardboard) battling to be the leader in this VR renaissance. Such displays allow for wholly different media experiences to be consumed, for example 360° video [47, 48], purely virtual experiences, and mixed reality spaces [147]. These VR HMDs typically accomodate non-HMD wearers in the room by presenting a view of the VR user's experience on a TV or monitor. For example the Oculus Rift mirrors its content on a computer monitor, whilst Sony VR provides a break-out box to convert the VR HMD video footage to be more appropriately viewed on a social screen[21]. Wider views of the virtual world the user inhabits have also been presented (see Figure 2.14), allowing social viewers an understanding of the context in which the VR user resides[22]. Whilst those in the same space as the VR HMD wearer can have an awareness of what the VR HMD user is experiencing, this awareness is not reciprocal, with the VR HMD visually cut off from those in the shared space.

Immersion in VR is typically quantified through the user's sense of presence, as coneptualized by Slater [197] as *place and plausibility illusion*. Presence can be affected by the

[21] www.eurogamer.net/articles/digitalfoundry-2015-playstation-vr-external-processor-revealed
[22] www.uploadvr.com/watch-this-mixed-reality-streaming-obliterate-the-stigma-of-anti-social-vr/

Figure 2.14: Fantastic Contraption mixed-reality stream sample [185]. Those in the same physical space as a VR HMD user can see view their shared space as it exists in VR, externally with respect to the VR HMD wearer.

rendering quality of the scene, the quality of the HMD's head tracking, and even how users interact with virtual objects. It can be increased through natural interactions with objects as they occur in the real world [109]. Presence can be measured in a multitude of ways, for example through brain activity, physiological measures or more traditional qualitative measures [218]. Many of these measures involve application-specific questions, however there are questionnaires that are generalized and widely used in literature e.g. Igroup Presence Questionnaire (IPQ) [190].

2.4.2 Problems with VR HMD Usability

Whilst the immersion provided by VR HMDs is their greatest strength, it is also their most significant weakness; when wearing an HMD, one's visual (and often auditory) connection to the "outside" world is diminished, promoting strong feelings of presence in the virtual environment. Even tasks as simple as picking up a cup become difficult without visual reference. Moreover, users are denied an awareness of the proximity and presence of others in the room, thus impeding a VR users capability to socialize. Existing consumer HMD such as the Oculus Rift or Gear VR do not yet incorporate the sensors needed to adequately track hands, identify objects, track people or provide a wide-angle FOV of reality. However, the rapid development of add-ons such as the Leap Motion VR[23] suggest that in the near future

[23]leapmotion.com/product/vr

these HMDs will have the capability to sense reality. In this respect, the blending of real and virtual becomes a necessity.

2.4.3 Blended / Mixed Reality

The field of "mixed reality" refers to displays that inhabit a point between reality and virtual reality in the "Virtuality Continuum" [147, 146]. This continuum led to the definition of both Augmented Virtuality (AV), where a virtuality view is augmented with elements of reality, and Augmented Reality (AR), where a reality view is augmented with elements of virtuality. Depending on the amount of reality or virtuality that is incorporated, a display can inhabit a very different point on the continuum. For example, a minor augmentation to reality would be close to reality on the scale, while a major augmentation to reality would be nearer to virtuality (see Figure 2.15).

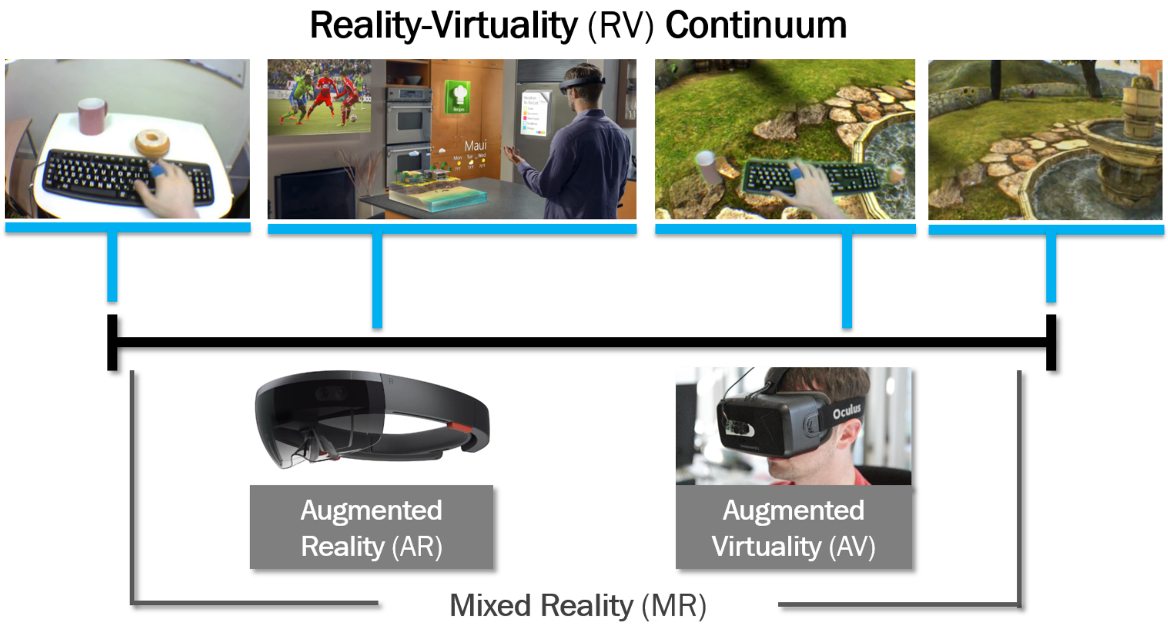


Figure 2.15: Example of Milgram's "Virtuality Continuum" [147, 146]. Augmented reality (with Microsoft Hololens pictured) and augmented virtuality (with the Oculus Rift DK2 pictured) are contained within the scope of mixed reality, with examples given of what the user might perceive at different points along the continuum.

AR has seen much research in recent years, building upon seminal work such as Navicam [176], with reality being augmented in ways that allow for novel interactive systems. In contrast, the concept of AV has received much less attention, partially due to the lack of good consumer HMDs. AV has been accomplished through the usage of chroma-key approaches toward interleaving real-world elements into a VR space. Early work in this area by Metzger [144] proposed a seamless integration of real-world human interfaces with the virtual world, using a HMD with a head-mounted camera and chroma-key image segmentation to enable video see-through. He proposed a small inset view of reality within the virtual world for a permanent view of reality, as well as the potential for making this view transparent, so that users could see through the virtual world image to a real world image.

Head-mounted cameras have been frequently used to capture reality e.g. Steinicke *et al.* [204] chroma-keying to the user's body, presenting the user's hands and body in an ego-centric view of virtuality. More recently, head-mounted depth cameras have allowed for hand tracking such that virtual representations of hands or objects are now becoming feasible [206], while room-wide sensors such as the Microsoft Kinect allow for user tracking, gestures and physiological measures, all of which could potentially be used to augment virtuality with information about reality that cannot necessarily be captured from a head-mounted camera. There remains the question of managing this augmentation of virtuality i.e. managing traversals or transitions within the virtuality continuum as discussed by Davis *et al.* [43]. Most research has examined mixed reality boundaries [16] where physical boundaries mark crossovers between mixed and virtual reality [70]. Where an interaction spans distinct points on the mixed reality continuum, it is termed a *transitional interface*. The importance of continuity in transitional interfaces has been highlighted, as well as the lack of a theoretical guideline for when to make these transitions [34], and how much to transition by.

2.4.4 Mixed Reality for Social Presence

Mixed reality experiences can also support social presence, and thus at-a-distance communication and interaction. Social presence refers to "the degree of salience of the other person in the interaction and the consequent salience of the interpersonal relationships" [196], with the level of social presence noted to "increase as the quality and the capability of the communication medium increases, from written, text-based media to face-to-face media..." based on an "individuals' perception of the medium to connect them to each other and create sociable, warm, and intimate interaction" [29]. Note that social presence is distinct from presence (place and plausibility illusion, referring to the sense of presence in a virtual world). For example, Room2Room [171] used room-wide sensing to capture those wishing to communicate, with projectors utilized to render those persons at-a-distance, as seen in Figure 2.16.

Combined with room wide sensing, VR HMDs have the capability to create shared mixed-reality experiences where those you are communicating with appear to be in the same virtual space as yourself, rendered with perceivable depth (in contrast to Room2Room, where the only depth perceived was on the basis of the furniture the user was being projected on to), potentially fostering intimacy and togetherness. In order to facilitate this communication, aspects of presence, location, identity and facial expressions may all play an important role in embodiment [14, 13]. Indeed there now exist shared at-a-distance VR media experiences in the consumer domain (see Figure 2.17).

Figure 2.16: Room2Room [171] system, where projects and Kinect sensors are used to create augmented reality experiences where geographically separated participants can communicate with each other, projected onto various elements of the available physical space, in this case available seating.

CineVEO[24], Oculus Social Alpha[25] and Convrge Cinema[26] all allow VR HMD users to attend a multi-viewer virtual cinema screening, typically using customisable avatars in place of people due to the current lack of standardised sensors for externally capturing the VR user. VR and AR displays also allow for potentially richer ways of communicating at-a-distance, ways which have the capability to mimic how people communicate in reality. For example, using room-wide sensing such as the Microsoft Kinect could allow for telepresence in VR at-a-distance, where multiple people could share a mixed reality space. Combining the potential for shared media experiences with such technology could provide more immersive and more intimate experiences at-a-distance.

To what extent can viewing media content together in this way approximate the experience had when physically co-viewing together? Instead of watching the living room TV, or going to a local Cinema, soon consumers will be able to put on an HMD and find themselves in experiences such as their own personal at-a-distance Cinema, or a 360° video of their favourite film [48]. Will the immersion these experiences provide help or hinder socialization at-a-distance?

[24]http://www.mindprobelabs.com/
[25]http://www.engadget.com/2015/10/28/oculus-social-alpha-delivers-group-watching-to-virtual-reality/
[26]http://www.convrge.co/

(a) CineVEO

(b) Oculus Social Alpha

(c) Convrge Cinema

Figure 2.17: Examples of at-a-distance VR HMD Cinema experiences currently available: (a) CineVEO has viewers represented by human avatars, with viewing occurring in immersive locations (e.g. 60s drive-in, Haunted Valley) (b) Oculus Social Alpha has viewers represented by humanoid/animal floating heads, with viewing occurring in a small cinema setting (c) Convrge Cinema with user-generated 3D avatars in stylised virtual worlds. In all cases head movements are transmitted and 3D positional audio communications are possible between viewers.

2.4.5 SUMMARY OF COLLOCATED AND AT-A-DISTANCE VR HMD USE

For VR HMD use in the home, there are two key issues. Firstly, how can basic interactions with reality be enabled, without unduly impacting sense of presence in virtuality. And secondly, how can multi-user interaction and shared experiences be facilitated when some users might be wearing VR headsets, whilst others observe on TV? Can an awareness as to the presence and proximity of others in the home be provided without impact the VR experience? This forms the basis of RQ 5.

For use at-a-distance, there is the potential for VR HMDs to change how media content is consumed with friends and family at-a-distance, given the advances they offer in terms of both the immersiveness of the media being consumed (e.g. 360° content), and their capability to make users feel present in a shared mixed reality virtual space. There is an opportunity to provide social and shared at-a-distance media experiences that go beyond what is possible with previously discussed VMC approaches. For example attending a virtual cinema, with a partner appearing to be present and seated next to the VR HMD wearer, is now technologically feasible. To what extent would this use case motivate VR HMD adoption, and how would such usage compare to existing TV at-a-distance behaviours in terms of the impact on a relationship? This forms the basis of RQ 6.

2.5 OUTCOMES FROM LITERATURE

This review has examined the state-of-the-art with respect to collaboration, social TV, and VR to demonstrate the problems faced in consumer media technology with respect to socialization and shared use. As such, the research in this thesis will explore six Research Questions across the domains of social and shared TV and VR HMD use, in the home and at-a-distance.

Research Questions (RQ) 1, 2 and 3 ask:

RQ 1 Are existing single-user TV interfaces suitable for multi-user use?

RQ 2 How can TVs support both shared and independent use?

RQ 3 Can TVs provide an awareness of others' collocated multi-screening activity without disrupting existing usage?

The research reviewed in Section 2.1 and Section 2.2 shows the social and shared nature of the living room TV, and discusses how research in collaboration could provide the foundations to enable shared and multi-user use of the TV. Three avenues of investigation are identified. Firstly (RQ 1) existing TV interfaces could be shared, through enabling mediated and concurrent interaction. Secondly (RQ 2) novel display technologies such as multi-view displays could enable both shared and independent activity on a single shared display. Thirdly (RQ 3) the closed-off activities of others in the room could be made more accessible and shareable by using the TV to provide awareness of multi-screen activity utilizing screen mirroring.

Therefore, the research in Chapter 3 investigates RQ 1, examining the extent to which an existing TV EPG interface can be shared in a small intimacy group, using social decision schemes. Chapter 4 then answers RQ 2, by examining how to design interactions for multi-view displays to enable both shared, and private/independent, activities on a single shared display. The research in Chapter 5 then investigates RQ 3, investigating how multi-screen activity can be shared on existing TV displays (Section 5.1), before then examining the effect this has on existing TV viewing, and how multi-screen activity can be shared on a multi-view display (Section 5.2).

Research Question 4 asks:

RQ 4 How can TVs support synchronous at-a-distance use with a partner?

The research reviewed in Section 2.3 shows the utility of synchronous at-a-distance TV experiences, and identifies the key challenge of demonstrating the feasibility of enabling at-a-distance TV experiences in existing smart TVs. In overcoming such a challenge, ecologically valid insights into the effect of different media types on relationships, and preferences regarding communication at-a-distance, would become possible. The research in Chapter 6 investigates RQ 4, by developing a synchronous at-a-distance TV system built on-top of an existing smart TV platform.

Research Questions 5 and 6 ask:

RQ 5 Should VR HMDs provide the ability to be aware of, and engage with, others in the same room, and how?

RQ 6 How are VR HMDs likely to change the nature of synchronous media consumption at-a-distance?

The research reviewed in Section 2.4 demonstrates that there are two key issues with respect to VR HMD use in the home. Firstly, general usability issues must be solved, regarding an interaction with, and awareness of, others in reality (RQ 5). Secondly, applications of VR HMD at-a-distance have the potential to surpass TV at-a-distance in terms of both immersion, and the fidelity of communication involved (RQ 6). As such, Chapter 7 investigates

RQ 5 by first surveying existing VR HMD users on usability impediments, confirming the necessity of incorporating the presence of others in the same physical space. It then evaluates techniques for augmented virtuality based on user engagement, bringing those in the room into virtual reality as and when necessary. In Chapter 8, this mixed reality approach is used to create immersive synchronous at-a-distance VR HMD experiences where a VR HMD wearer and their partner inhabit a shared mixed reality space. An evaluation then compares these virtual experiences with synchronous at-a-distance TV usage.

3. Shared Control of the TV

Since 1955, interaction with the television has iterated upon a single device that is now considered a *de facto* standard: the remote control. It is a device of ubiquity in the living room and has a host of associated management behaviours; it can be passed, taken, shared, relinquished, hidden or even denied. However, it is no longer the only means (ignoring the physical controls located on the TV) of interacting with a smart TV. Gestural and voice interaction features have become commonplace in high-end smart TVs, and often these TVs are bundled with multiple remote controls of varying capabilities. For example Samsung SmartTVs[1] typically support gesture and voice control, with both standard and touchpad remote controls bundled, whilst set-top boxes such as the Xbox One[2] build on previous work regarding voice and gesture controls [150] to provide such capabilities to owners of older, non-smart TVs as well. In addition, mobile devices such as smartphones and tablets often have dedicated applications for interacting with different smart TV brands (e.g. the Bang and Olufsen "BeoRemote" remote control app[3]), as well as more generic capabilities for interacting with any media system (e.g. Android devices with IR blaster support for remote control emulation[4]).

In this way, the potential for concurrent multi-user interaction with the TV has increased dramatically. The constraint of "one user at-a-time", which was enforced by the existence of one physically shared remote control, is being eroded, with new possibilities for multi-user use becoming a reality. However, as a consequence, existing behaviours and familiar interactions are potentially being discarded without due consideration. This new scenario introduces two issues: concurrency of use and management of use.

[1]http://www.samsung.com/us/2013-smart-tv/
[2]http://www.xbox.com/en-US/xbox-one/entertainment
[3]http://www.bang-olufsen.com/en/picture/apps/beoremote_app
[4]http://www.slashgear.com/which-phones-let-me-control-any-tv-24338249/

Concurrency of use In providing systems that support concurrency, additional complexity may be introduced, and user's mental models of the media systems they interact with may be undermined. In the case of discrete, grid-based interfaces (e.g. where button presses enact discrete navigation events) concurrent use might lead to destructive combinations of inputs (e.g. one user attempting to change from the EPG to the on-demand view, whilst another was browsing the EPG). In the case of multi-pointer / cursor-based interfaces, this problem is potentially compounded by the increase in both visual complexity, and the dexterity and coordination required to interact effectively.

Management of use In facilitating ubiquitous control and moving away from traditional behaviours for managing control, users' capability for managing who can interact with these systems may be undermined, for example parents taking the remote away from a child. Whilst systems such as the Xbox One have the capability to identify users, and thus the crude physical management of control could be supplanted by a more reactive and programmed form of management, there are a number of issues e.g. privacy concerns regarding always-on sensors in the living room. As such, there is scope for arguing that traditional behaviours for managing use be preserved in some fashion, and furthermore that the components of these traditional behaviours that are most important (in terms of usage and acceptability) be identified.

On this basis, this chapter investigates how existing grid-based TV interfaces, designed for control by one user at-a-time, can be used by multiple users. It does so with the assumption that the bottleneck of a single physical remote control no longer exists, looking at the relevance and usability of existing and new behaviours for managing, and sharing, control.

Research Question 1 asks:

> Are existing single-user TV interfaces suitable for multi-user use?

Section 3.1 describes a survey into how control of TVs is currently shared. This in turn informs Experiment 1 in Section 3.2, investigating how control of a grid-based EPG interface can be mediated and shared in small groups.

3.1 EXISTING BEHAVIOURS SURVEY

To gain an understanding of existing behaviours for sharing control in home media systems and their acceptability, a short survey was conducted, reaching 156 respondents in all (for demographics see Figure 3.1). The survey was sent out to available University mailing lists (covering staff and students) as well as online forums / social media, in late 2012, with printed copies distributed to respondents in demographics less likely to be reached via email.

	What is your age?						
Living status	18 to 24	25 to 34	35 to 44	45 to 54	55 to 64	65 to 74	**Grand Total**
Alone	4	9	9	1	2	2	27
Alone With Flatmates	1						1
Alone With Parents		1					1
With Children			3	1			4
With Flatmates	6	7					13
With Parents	11	6	1				18
With Partner	2	31	11	6	4	3	57
Partner & Children		10	8	12	4	1	35
Grand Total	24	64	32	20	10	6	156

Figure 3.1: Demographics of respondents, broken down by age and living status (gender omitted, however split was approximately 60-40 biased towards males).

Its intention was exploratory, consisting of questions (predominantly 5-point Likert-type) constructed to explore control methods, decision making and media consumption activities (see Appendix C for the full questionnaire).

3.1.1 DECISION MAKING IS PREDOMINANTLY DEBATE BASED

Respondents were asked to select which methods they used for decision making in different forms of intimacy group, as seen in Figure 3.2. These methods were based on discussed social decision schemes (see Section 2.1.5.4) and prior experience regarding viewing with others. Debate was selected by approximately two thirds of respondents, over double the responses of other available options, as seen in Figure 3.2.

Cohabitants, family and friends all shared similar distributions - these groups appear broadly similar in terms of how decision making is accomplished in group TV viewing. The exception to this is the spike of "Individual(s) in charge" for family groups, likely driven by parental control of TV viewing. An additional "Other" field was provided, with 11 comments, the majority of which stated that the respondents did not view TV socially with one or more of the prescribed intimacy groups. One respondent suggested a mitigation strategy they used for conflict resolution, namely that "If [there were] a clash of programmes, record one and watch the other. If selected programme is not of interest, find a different activity".

Figure 3.2: Responses to “In your experience, how are decisions most often made within the following groups, regarding choice of media (e.g. selection of a film, TV program, or game)?”.

3.1.2 Remote Controls Still Dominate

The majority of respondents (over two thirds) indicated that remote controls per device were the dominant interaction mechanism for their media systems (see Figure 3.3). Gesture interfaces and voice control were ranked last, with single-figure responses, indicative of their current lack of adoption.

3.1.3 Control Is A Commodity

The most relevant and interesting result of this survey was in two questions regarding how control was shared in home media systems and how acceptable these methods were (see Figures 3.4 and 3.5).

Participants were asked to rate hypothesised control management behaviours (and suggest their own if not appropriate). Of these, “first come, first serve”, “passing control around”,

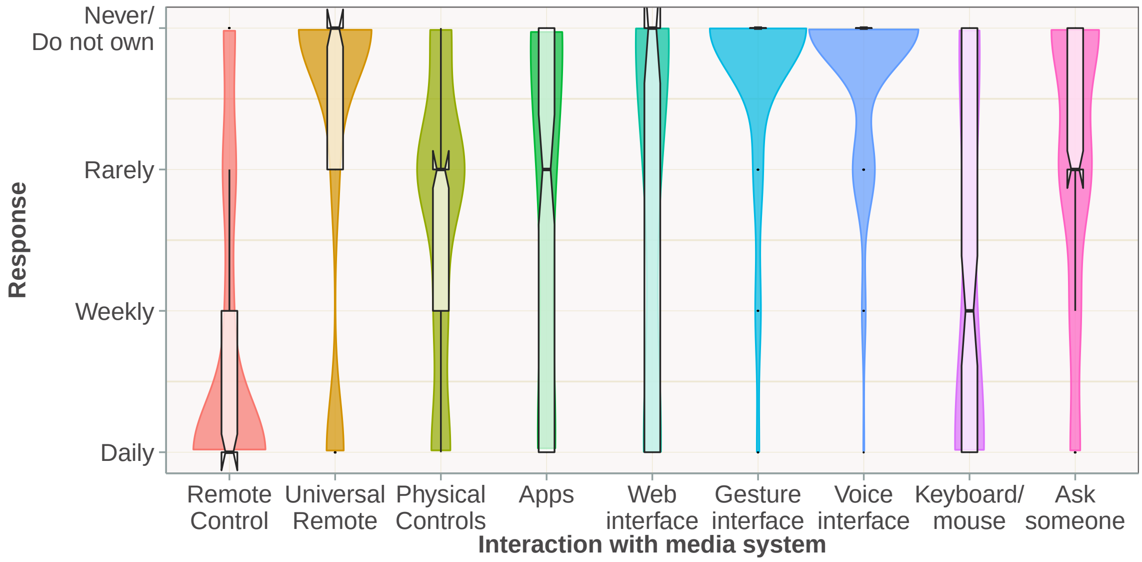


Figure 3.3: Responses to the question “Which control methods do you use to control your TV/set top box/media systems in your household currently?”. Responses were Likert-type five point scale, ranging from daily weekly, rarely to never. For an explanation of Violin plots, see Appendix A.

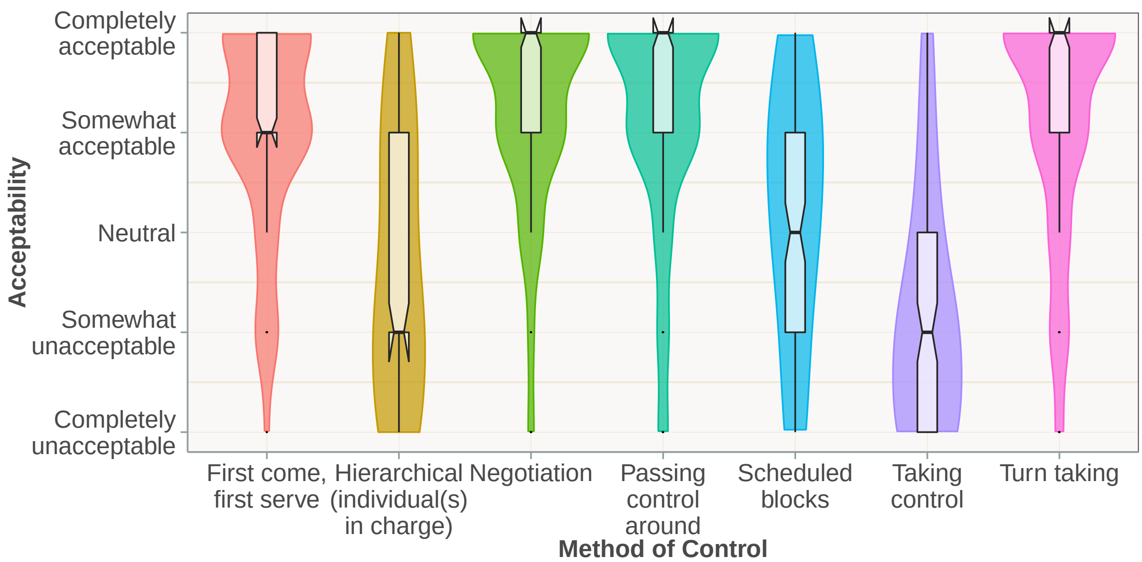


Figure 3.4: Responses to the question “How acceptable do you find the following ways of controlling media systems?”. Responses were Likert-type five point scale, ranging from completely unacceptable to completely acceptable, and converted into 0-4 scale for mean acceptability.

"negotiation e.g. asking for control" , and "turn taking" were the most used strategies, with "hierarchical (an individual is typically in control)" , "scheduled blocks for sharing control of the TV", and "taking the control from whomever currently has it" falling behind. This supported the view that control of these systems is a commodity or resource in and of itself. As the person currently in control plays a large part in dictating events, if you acquire control, you might be reticent to relinquish it; societal norms of fairness may, however, dictate that strategies be introduced to accommodate other's wishes and uses, hence passing control, turn taking and negotiation feature.

Of these frequently used control schemes, in terms of acceptability they were largely similar (see Figure 3.5). This suggests that the behaviours that have developed around control of these media systems have evolved towards ones that are broadly acceptable. They may not be perfect (for example, first come first serve featured ~60% of respondents in the somewhat acceptable or lower category), but people are familiar and comfortable with passing control, and negotiating amongst themselves, an indicator of the social nature of managing these systems.

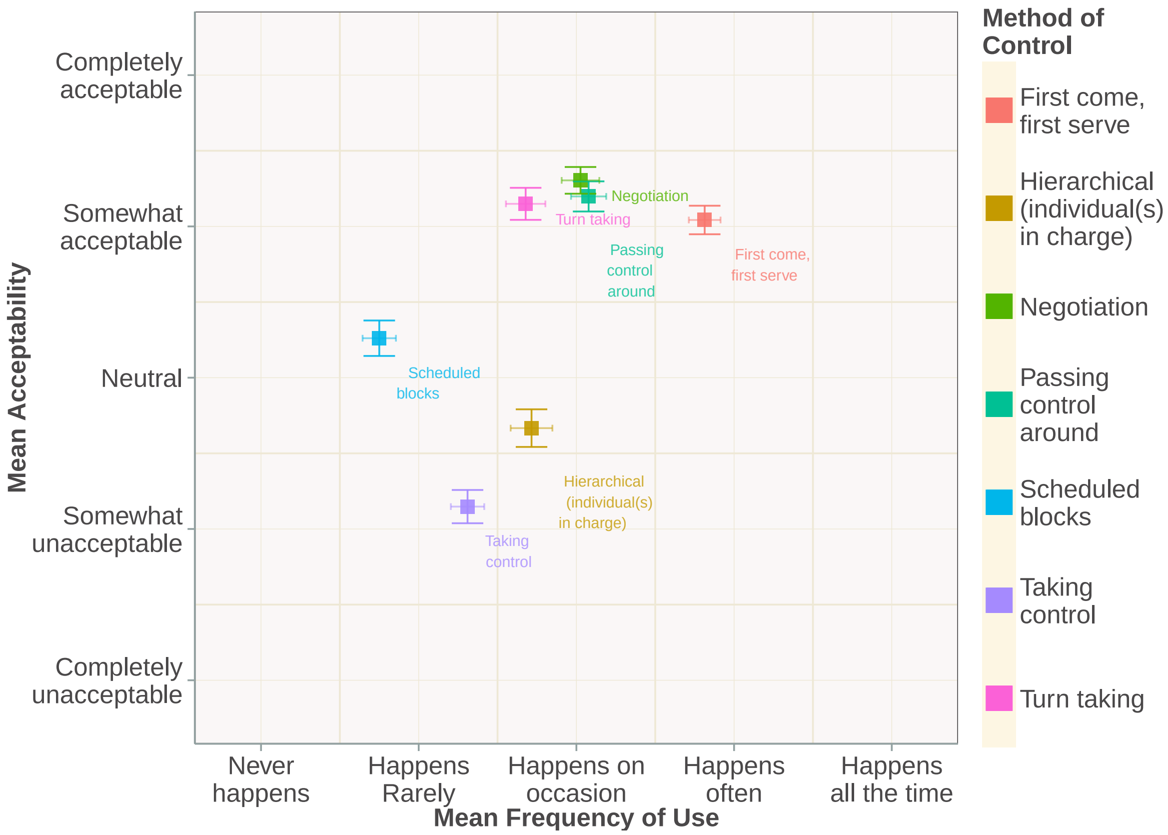


Figure 3.5: Plot of acceptability (mean of converted five point Likert scale to 0-4 scale for scoring, higher is better) against count of respondents that had previously responded to using that method of control often. Whiskers indicate standard error.

Of the less frequently used schemes, taking control was deemed unacceptable (~70% of respondents considering it somewhat to completely unacceptable), as was hierarchical control (~50% considering it somewhat to completely unacceptable).

3.1.4 SUMMARY OF SURVEY

From this survey, some understanding about current behaviours for managing control was established. In terms of current behaviours, whilst they ranked highly in terms of acceptability, their suitability in scenarios where the token of the single remote control was removed (e.g. gesture or device control) would be questionable - are these acceptable behaviours (such as passing control) to be marginalised in the face of allowing anyone control at any time, and how can systems be designed to handle such an eventuality? Were the control mechanisms that ranked poorly in acceptability (such as taking control) inhabiting those positions because they are inherently unacceptable, or just poorly represented in control of current media systems? These questions informed the following Experiment.

3.2 EXPERIMENT 1: MEDIATION OF CONTROL

Given the findings of the survey and the literature review, Experiment 1 was to develop a system for virtualizing control, such that it could be managed in software by users, to investigate RQ 1, which asked:

> "Are existing single-user TV interfaces suitable for multi-user use?"

To answer RQ 1, two perspectives were examined. Firstly, there is the extent to which existing behaviours could be retained and used to facilitate multi-user use of the traditional "one user at a time" TV interface. When there is no physical remote control to possess, how should the determination of which user is in control be virtualised and managed? Secondly, the constraint of having only one user interact at a time is considered. If the TV interface is receptive to inputs from multiple users simultaneously, will users self-mediate and self-manage their use of the TV within a group? Or will conflicts arise as users attempt to interact concurrently with an interface that is not designed to support this concurrency. And should the system intervene, or provide a means of mediating between inputs in such scenarios?

As such, two hypotheses arose from RQ 1, regarding single-user, grid-based TV interfaces:

H1 When concurrent inputs are possible, interaction will become prohibitively difficult, indicated by perceived workload, number of user interactions and user preferences, compared to interacting via a single shared remote control.

H2 Virtualizing the sharing of control will be comparable to interacting via a single shared remote control, in terms of workload, usability and user preferences.

The Experiment answers RQ 1 by examining two approaches to enabling multi-user interaction with a TV interface intended for use by one user at a time. H1 examines the feasibility of allowing for simultaneous inputs and concurrent interaction with a single-user TV interface. H2 examines the feasibility of virtualizing control and providing a digital means of managing who in the group is in control at any one time. In both cases, multi-user interaction is compared to the existing standard of a single, physically shared remote control. In this way, it would be established whether the "one user at a time" constraint should remain in place, and whether physical management of a token of control was necessary to enforce this constraint. Given this, usage was to be evaluated using a TV media interface designed for use by one user at a time, thus retaining the interface and mental models that users are familiar with. On this basis, concurrent use interactions and interfaces (e.g. using multiple pointers) were not considered. Thus the control scheme used was to be similar to that of a standard remote, supporting discrete directional actions (left / right / up / down) and selections.

For this study, 10 different control schemes were proposed (see Table 3.1 for details), broadly categorised as either retaining the constraint of "one user in control at a time" (hereafter "one user"), or allowing for multiple users to interact simultaneously (hereafter "everyone"). This was done to evaluate, in as much breadth as possible, the ways in which both approaches might be accomplished, in case of outliers that might prove effective. The "one user" schemes were based on existing behaviours: **passing**, **taking** and **turn taking**. Additionally, a variant of passing / taking was introduced: **lending**, essentially a hierarchical means of managing control where control could be lent out, and revoked, from an individual with authority. The **control** condition also fell into this category, being one remote control physically shared amongst participants.

The "everyone" schemes were introduced on consideration that, if everyone could concurrently interact with a single-user interface at any time, would an amount of self-organisation / mediation take over, thus demonstrating that system-based mediation of control was not necessary? As such, conditions were added allowing for **everyone** in control, **subsets** of control (where different group members had control of different functions, thus requiring cooperation), **hierarchy** (where one member's input would override that of the others), **plurality** (where selection decisions were based on majority votes but navigation was concurrent) and **blocking** (where members could selectively and temporarily block each other from control).

3.2.1 PARTICIPANTS

Three person intimacy groups (2 groups of friends, 1 group of cohabitants, 1 family group (siblings), 1 group of colleagues) were recruited, five groups in all, fifteen participants total (male=7, female=8, mean age=21.2, Standard Deviation (SD) age=3.5). These participants were to be evaluated across two sessions in a repeated measures (within-subjects) design,

Condition	**Description**	**Implementation Details**
		One user at a time
A: Control condition	One person in control	*A single device placed on the table with participants instructed to use it as they would a normal remote*
B: Lending	Ability to lend control and take it back	*Two buttons were used to explicitly lend/retrieve control*
C: Passing	Control can be passed around	*Two buttons were used to explicitly pass control to the other participants*
D: Taking	Control can be taken off them	*Two buttons were used to explicitly take control from the other participants*
E: Turn-taking		*Control was passed every 10 seconds*
		Multiple users (Everyone contributes to control)
F: Everyone	Everyone has control	*All devices in control at all times*
G: Plurality	Majority rules voting for selections	*When a selection was made participants were blocked from browsing, and would have 5 seconds to respond positively to confirm the selection or it would be denied*
H: Hierarchy	Designated individual outranks the others and can override their control	*One participant was randomly selected to outrank the others, when they used the system the others were blocked from control*
I: Subsets	Everyone has a subset of control	
J: Blocking	Can block other people temporarily	*Two buttons were used to selectively block participants for periods of 4 seconds*

Table 3.1: Experimental conditions by category. “One user at a time” denotes one person in control at any one time, while “Multiple Users” denotes everyone being in control simultaneously.

with five conditions in one session, and five in the second. Each session was one hour long, with conditions randomly assigned to sessions (with similarities in terms of order requiring re-assignment) as the number of Conditions and groups precluded counter-balancing. Additionally, participants were given time to trial each mediation of control scheme until they felt comfortable in its operation.

3.2.2 TASK DESIGN & IMPLEMENTATION

The task was to schedule what programs the group wished to record for a given 3-hour time period (once per condition), using an Electronic Programme Guide (EPG). For each condition, they were assigned a three hour block in which they were to pick and choose programs to record for viewing. The program listing was generated from scraped listings of UK and New Zealand television, to ensure an element of unfamiliarity to the schedule, and randomly assigned into hour long or half hour long blocks. Conditions were assigned pseudo-randomly to time-periods, with no condition using the same time period more than once. The EPG used for this task was Windows Media Center (WMC)[5]. This was done primarily to ensure ecological validity using a discrete grid-based interface comparable with home media systems and existing smart TVs.

In terms of the virtualized management of control, Android phones with a basic remote interface were used (see Figure 3.6). These devices provided users with the ability to browse

[5]http://windows.microsoft.com/en-GB/windows7/products/features/windows-media-center

Figure 3.6: The user interface for controlling the system, and managing control. Three Android devices were used as remote controls to a Windows Media Center interface (pictured right). The bottom left/right buttons change function depending on the condition being evaluated.

through the EPG, confirm recordings and manage control through two buttons whose function changed depending on the mediation of control scheme being used. For example, in the passing control conditions, these two buttons would refer to the other two participants by name, allowing the user to select to whom to pass control. Additionally, the devices gave feedback as to who was in control and an overview of the main display (the WMC interface). The WMC EPG itself was presented on a projector display, with participants arranged sociopetally around the display in a mock living room (see Figure 3.7). Ecological validity was strived for in a number of ways: the use of WMC ensured an ecologically valid single-user EPG interface, representative of media systems used in the home currently. A laboratory room was mocked up to resemble a living room, with natural lighting, comfortable sociopetal seating and a large display. For a video of the system in use, see [6].

Figure 3.7: Living-room-like space used for conducting evaluations. Left: sociopetal seating arrangement. Right: Projector display with WMC.

For implementation details for each condition, see Table 3.1. Task duration was enforced through the use of 3 hour blocks in the EPG (which took ~3min to schedule, with an additional unlimited time for training that usually lasted for around ~3 min). As such each control scheme was typically used for ~6min (so ~30min per session, ~25min for questions, ~5 for briefing). There was no time pressure; participants carried out the task to completion at their own pace. This task duration was deemed acceptable because people interact with EPG interfaces often, but for short intervals; it is the nature of both the time-series data, the narrow range of time they are interested in, and the aim of the task. The task itself is well understood by users, short to conduct, and provided motivation for multiple users to interact concurrently (conflicting media interests), suiting this usage as a novel and ecologically valid task.

[6]https://www.youtube.com/watch?v=PYyBx9KWnoU

3.2.3 MEASURES

Participants were recorded for the duration of the experiment by an HD camcorder facing the group from the front, while instrumented system usage metrics (action counts: number of button presses per user) were also captured to measure intra-group dominance (the disparity between users within their groups i.e. to what extent did one user dominate usage of the system). Users were presented with questionnaires on the completion of each condition, including workload (NASA TLX [87]), usability (System Usability Scale (SUS) [24]), and 5-item Likert-scale questions covering the acceptability of control schemes and preferences regarding their use. Additionally, users were asked to rank the conditions in order of preference at the end of the study, with post-condition and post-experiment interviews used to further understand user preferences and dislikes regarding control schemes. See Appendix D for experimental materials (question set and plain language statement given to participants).

3.2.4 RESULTS

Unless otherwise stated, a repeated measures ANOVA (conducted using linear mixed-effects model fit by maximum likelihood (*lme()* in R) was performed with a *post hoc* Dunnett's test (comparison of every condition with the control, which was analogous to a single physical remote control). For non-parametric data, an Aligned-Rank Transform was first performed such that parametric tests could then be used [232], signified by (ART). See Appendix A for more details of the statistical testing used in this thesis. Conditions found as significantly different ($p<0.05$) from the control in the Dunnetts test are listed in each Figure.

3.2.4.1 QUESTIONNAIRES

A summary of the questionnaire results can be seen in Table 3.2. The "one user" schemes appeared to be functionally equivalent to each other across a variety of metrics, with comparable SUS scores (see Figure 3.8), TLX scores (see Figure 3.9 for frustration and Figure 3.10 for overall workload), and action counts (a measure of how much effort was required to use the system, see Figures 3.13 and 3.12). Additionally, Conditions B, C, and E all achieved superior mean rankings than A (see Figure 3.14). Indeed, these Conditions could rarely be separated from the control.

Conversely, the "everyone in control" conditions were broadly found to be significantly worse than the Control in SUS scores, TLX mental demand, temporal demand, effort, frustration, and self-rated satisfaction (see Figure 3.11) with using the system.

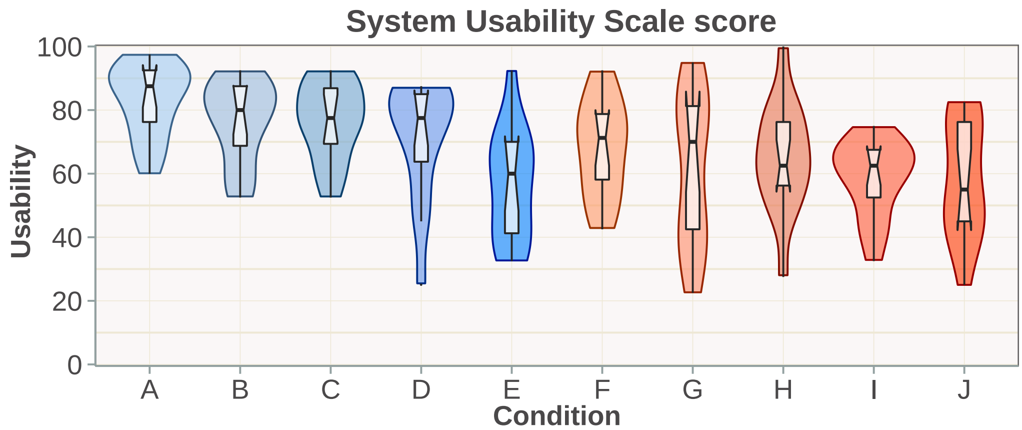


Figure 3.8: Overall SUS Score (a ten-item Likert-type questionnaire for assessing usability, higher is better) - $\chi^2(9) = 36.80, p < 0.01$ **Dunnetts:** E, F, G, H, I, J. Blue shades: “one user” conditions. Red shades: “everyone” conditions.

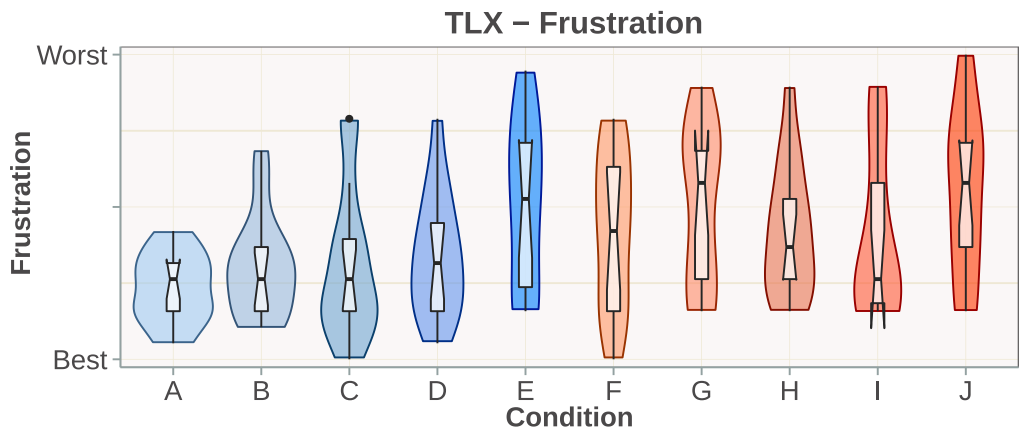


Figure 3.9: TLX Frustration Question by condition, lower is better - $\chi^2(9) = 33.93, p < 0.01$ **Dunnetts:** E, F, G, J. Blue shades: “one user” conditions. Red shades: “everyone” conditions.

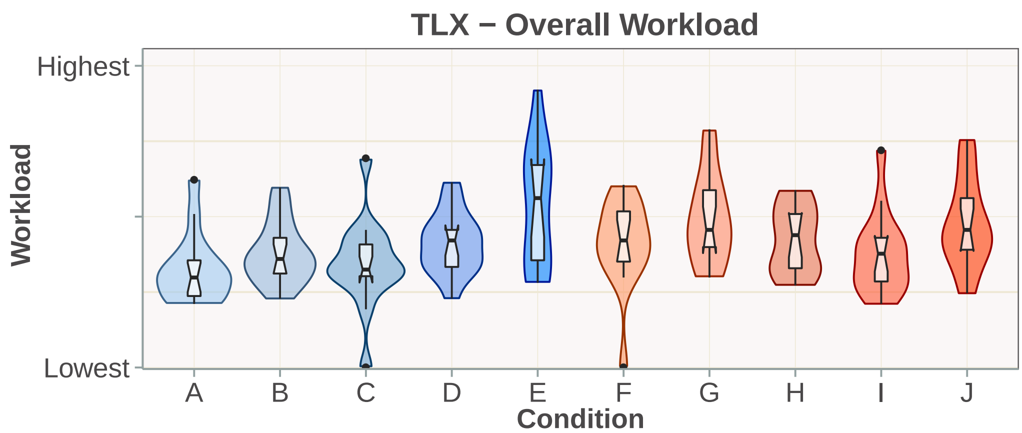


Figure 3.10: TLX Overall Workload by condition, lower is better - $\chi^2(9) = 43.90, p < 0.01$ **Dunnetts:** E, G, J. Blue shades: “one user” conditions. Red shades: “everyone” conditions.

Question	RM ANOVA	Dunnet's Test ($p < 0.05$)
MISC: I felt in control whilst using the system to perform the task	(ART) $\chi^2(9) = 11.61, p = 0.24$	NA
MISC: I felt the system was fair	(ART) $\chi^2(9) = 14.85, p = 0.095$	NA
MISC: This system gave me an efficient way to perform the task	(ART) $\chi^2(9) = 28.76, p < 0.01$	A-E, A-F, A-G, A-J
MISC: I was satisfied with my experience using the system to accomplish the task	(ART) $\chi^2(9) = 27.03, p < 0.01$	A-E, A-F, A-G, A-H, A-I, A-J
MISC: I was comfortable using the system	(ART) $\chi^2(9) = 34.04, p < 0.01$	A-E, A-F, A-G, A-H, A-I, A-J
MISC: How acceptable did you find this as a means of sharing control of a media system with others?	(ART) $\chi^2(9) = 24.47, p < 0.01$	A-E, A-J
TLX: Mental	$\chi^2(9) = 45.08, p < 0.01$	A-D, A-E, A-F, A-G, A-J
TLX: Physical	$\chi^2(9) = 9.25, p = 0.41$	NA
TLX: Temporal	$\chi^2(9) = 66.20, p < 0.01$	A-E, A-G, A-J
TLX: Performance	$\chi^2(9) = 13.47, p = 0.14$	NA
TLX: Effort	$\chi^2(9) = 37.22, p < 0.01$	A-E, A-G, A-J
TLX: Frustration	$\chi^2(9) = 33.93, p < 0.01$	A-E, A-F, A-G, A-J
TLX: Overall Workload	$\chi^2(9) = 43.9, p < 0.01$	A-E, A-G, A-J
SUS: System Usability Scale	$\chi^2(9) = 36.8, p < 0.01$	A-E, A-F, A-G, A-H, A-I, A-J

Table 3.2: Questionnaire responses. TLX refers to NASA TLX workload scales [87], SUS refers to System Usability Scale [24]. MISC refers to questions written specifically for this study. Green shaded boxes throughout this thesis indicate statistical significance ($p < 0.05$). (ART) indicates an Aligned-Rank Transform was used (see Appendix A).

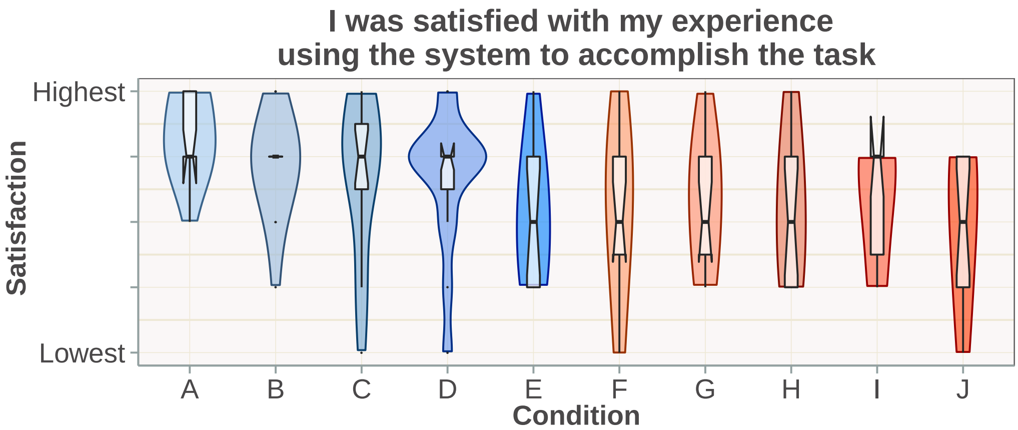


Figure 3.11: "I was satisfied with my experience using the system to accomplish the task" - (ART) $\chi^2(9) = 27.03, p < 0.01$ **Dunnetts:** E, F, G, H, I, J (letters refer to conditions in Table 3.1). Blue shades: "one user" conditions. Red shades: "everyone" conditions.

This trend continued in the instrumented metrics, with higher mean action counts (see Figure 3.12), indicating that instead of self-mediation, users were having to expend greater effort to counteract each other's inputs.

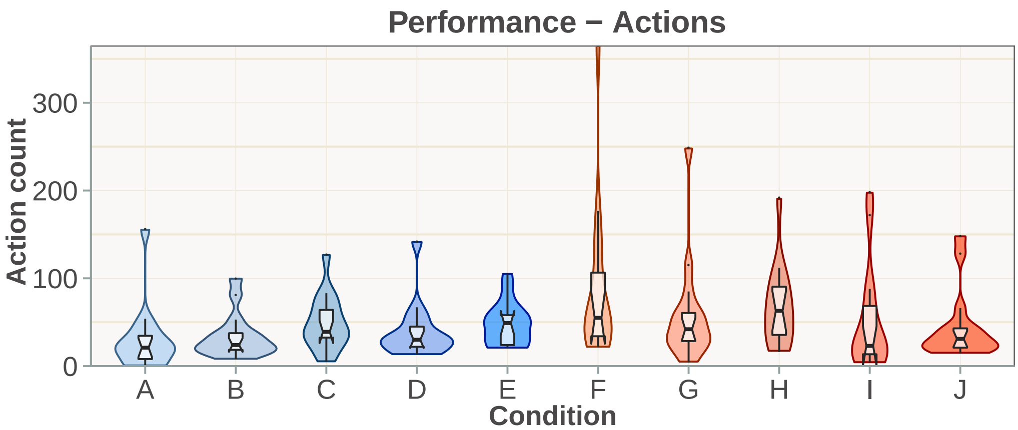


Figure 3.12: Mean actions across users by condition - $\chi^2(9) = 23.30725, p < 0.01$ **Dunnetts:** F. Blue shades: "one user" conditions. Red shades: "everyone" conditions.

3.2.4.2 DOMINANCE

Dominance here refers to the disparity between users within their groups, in terms of instrumented metrics, specifically action counts (button presses). This was examined as a potential metric for measuring fairness: to what extent did one user dominate usage of the system. Shareability [96] has been shown to be important in terms of impacting equity of control [181]; barriers preventing shareability thereby foster interpersonal dominance within groups (as seen for example in [7]).

In Figure 3.13 it can be seen that by action count, condition E (turn taking) exhibited the least dominance, which is to be expected when each participant is given the same amount of time in which to operate. Compared to the control condition, the "one user" conditions exhibited lower dominance behaviour, in contrast to the "everyone" conditions.

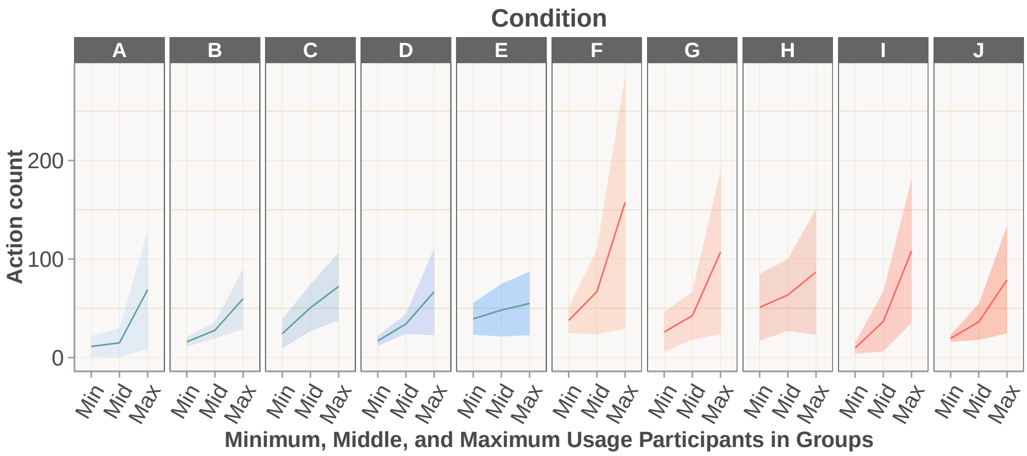


Figure 3.13: Dominance by actions - Plot of three values per condition: mean of (max / median / min) action counts across groups, with shaded standard deviation - $\chi^2(9) = 21.11, p < 0.01$ **Dunnetts:** F. Blue shades: "one user" conditions. Red shades: "everyone" conditions.

The "one user in control" conditions by and large exhibit low dominance, a level that is perhaps socially acceptable or even necessary for a group task. The results for Condition D partially confirm this: in this condition, participants were allowed to take control whenever they wished, therefore it might be reasonable to presume that if one participant was dominating to the detriment of the experience, the others might have taken control, given their familiarity with their fellow participants.

In contrast the "everyone in control" conditions exhibited greater dominance behaviour than the "one user" conditions, an indicator of their chaotic nature (reported in most post-condition interviews), with one user effectively being required to actively and continuously assert control over the system to counteract the discordant nature of multiple simultaneous inputs.

3.2.4.3 CAVEATS & EDGE CASES

There were some notable exceptions to these observations. For example, Condition G (majority rules for selections) came out favourably in subjective metrics; participants indicated that although they disliked the underlying "everyone" scheme they enjoyed the fairness of voting to make a selection (see Figure 3.14). This was a confound where mediating selection was evaluated, not control. Similarly, Condition E (turn taking) frequently fared poorly (e.g. featuring the highest mean TLX temporal demand).

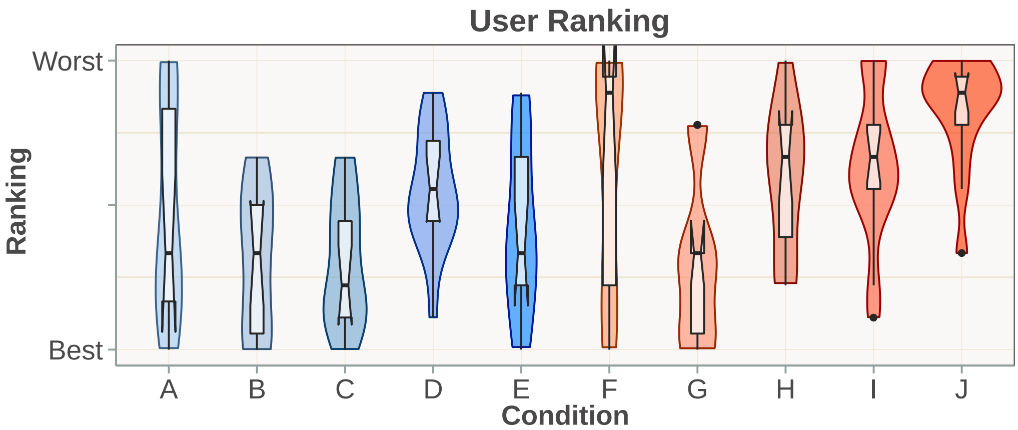


Figure 3.14: Ranking (lower is better) - Friedman test $\chi^2(9)$ = 37.20, p $<$ 0.01, Wilcoxon sign rank test with Bonferroni correction showed no statistically significant differences (p $>$ 0.05)

Enforced fairness via time-slicing may have been confounded by the necessity to time-slice at small intervals to allow participants to experience the control scheme within the duration of the task. Additionally, questions are raised regarding the acceptability of taking control (Condition D), whose mean ranking was the only ranking of the "one user" conditions to be worse than the control.

3.2.4.4 SPEECH

The audio track was extracted from video recordings of each group and analysed in order to examine whether the amount of speech varied across Conditions (see Figure 3.15).

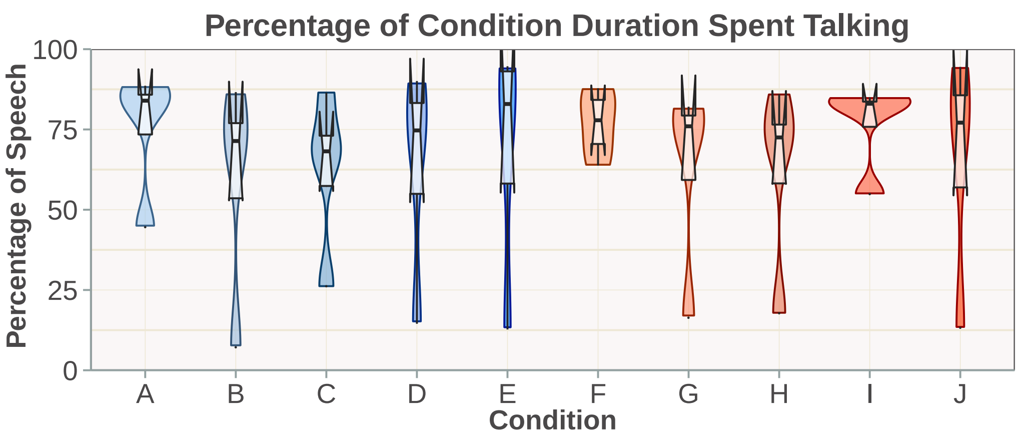


Figure 3.15: Percentage of session spent talking, by group and Condition - Friedman test $\chi^2(9)$ = 8.1, p= 0.5. N.B. Recordings for Group 5 were omitted due to incomplete recordings.

The amount of speech was calculated via an Audacity[7] plugin for calculating the amount of silence, with the threshold adjusted manually for each clip to match environmental noise. There were, however, no significant differences, with speech primarily motivated by a discussion of the EPG content, and only secondarily by the mechanics of browsing said content.

3.2.4.5 INTERVIEW FEEDBACK

Excerpts from interviews have been grouped into related discussion themes. Themes were identified based on both novelty (i.e. unusual comments indicative of outliers) and frequency (where similar comments appear across multiple groups). G: refers to group, C: refers to condition. Quotes have been broken down into groups due to the complexity of the recorded discussions preventing a breakdown by participant.

DESIRE FOR CONTROL For one participant, being in control was important and not being in control disquieting:

> "I liked the ones where I was in control, I liked being the one in control" *G:2, C:Debrief*

Conversely, in two of the groups there were participants that had no interest in being in control, for example because of a disinterest in making decisions or even a dislike in sharing viewing:

> "I don't like being in charge, so I'm happy to let someone else have the responsibility" *G:2, C:F*
> "I liked it because he was in control, and can watch what he wants to watch" *G:2, C:A*
> "I don't want to share TV with them!" *G:3, C:D*
> "At the end of the day, I prefer to choose my own programs, I don't like watching TV with other people.. I don't want to choose who to give control to" *G:3, C:C*

"EVERYONE IN CONTROL" ENCOURAGES DOMINANCE Three groups provided similar complaints regarding the discordant nature of the everyone in control conditions, with participants explicitly noting the presence of dominance behaviour in this condition:

[7] http://audacity.sourceforge.net/

> "I always find this a bit annoying in computer games where you both have control and you invariably hit the wrong thing, because you both go down at the same time, so you make mistakes more trying to get to the same thing" *G:2, C:F*
> "It's mental" *G:1, C:F*
> "One person has to take the lead because you can't all operate at the same time" *G:3, C:F*

However, two groups noted the difference voting made to the "everyone in control" experience:

> "For me, it was about everyone having the same options and opportunities to pick what to see, I would prefer to see something everyone prefers to watch" *G3, C:Debrief*
> "I think this is my favourite, because it's like.. I find comfort if I don't get what I want but the other two are getting what they want... It's fairer, especially amongst friends or family" *G3, C:G*
> "I liked the majority voting, not because I thought it was great, I just liked the idea of a vote being used" *G1, C:Debrief*
> "I [wanted] the voting [but with] one person having overall control and being able to shift control to other people and take it back" *G1, C:Debrief*

3.2.4.6 "One User At A Time" Preferred

Four groups noted and preferred the simplicity of the "one user in control" schemes and their associated management schemes, e.g.:

> "Sometimes I actually don't want to speak, I don't like interrupting people speaking, so if they are speaking if I wanted to take control I'd probably just press the button and whoever was in control would give it to me if they wanted" *G:3, C:D*
> "It was good to be able to transfer the remote" *G:2, C:D*
> "One person in control is the best, because we can all talk to each other and just one can pick" *G:4, C:Debrief*
> "One person in control, turns taken.. simplicity and fairness" *G1, C:Debrief*

However, there were concerns regarding the usefulness of some of these schemes:

> "I feel like this is just mechanising something you can do naturally" *G:2, C:G*
> "I think in the end everything is too tiring for me, I prefer to give control to anyone, quite a lot of things are interesting to watch." *G:3, C:Debrief*

3.3 CONCLUSIONS AND RESEARCH QUESTION 1

Regarding H1:

> When concurrent inputs are possible, interaction will become prohibitively difficult, indicated by perceived workload, number of user interactions and user preferences, compared to interacting via a single shared remote control.

The results supported this hypothesis, with the "Everyone in control" conditions proving poorly suited to concurrent use. These conditions exhibited worse mean rankings, poor SUS scores, higher TLX frustration, as well as greater dominance behaviour (excluding Condition G). This suggests that single-user media systems should not be opened up to concurrent use, and places a question mark over the usability of new input mechanisms such as phones with IR support, and thus remote control emulation, if there is no means of mediating between multiple concurrent inputs.

Regarding H2:

> Virtualizing the sharing of control will be comparable to interacting via a single shared remote control, in terms of workload, usability and user preferences.

The results broadly supported this hypothesis. Lending, passing, and taking control were, at worst, comparable to having one physical shared remote. These conditions exhibited comparable workload, usability scores, and dominance behaviour whilst mean user rankings were moderately better than that of the control (Condition A). That these schemes approach the usability of the single remote control users are familiar with suggests that mediation of control schemes can be created that are, at least, comparable to the existing standard of a single remote control for input, and are preferred by users due to the flexibility provided by no longer physically managing a single remote control. Because of this, it is apparent that existing behaviours for managing control remain relevant given the virtualization of control. Moreover, the "one user at a time" Conditions proved broadly superior to "everyone in control" Conditions, exhibiting statistically better SUS ratings and mean rankings (aside from Condition G), confirming the view that the primary differentiator between conditions was whether they allowed concurrent inputs versus allowing one user to interact with the underlying media system at a time.

Research Question 1 asked:

> Are existing single-user TV interfaces suitable for multi-user use?

To answer RQ 1, first it was necessary to examine how shared use of existing TV interfaces is currently conducted. In an exploratory survey, a set of behaviours was established as occurring when sharing control of a TV interface, through turn taking, passing control, taking control, and hierarchical control. These behaviours were categorised and virtualized along with other potential behaviours given the possibility of concurrent and simultaneous interaction, such as everyone having control, and voting to make selections. An experiment then examined the effect that such behaviours had on browsing an EPG listing in intimacy groups, in terms of usability, workload and user preference.

The results of this Experiment suggested that using a subset of the virtualized "one user" behaviours, namely passing, taking and lending control, could facilitate multi-user usage whilst preventing the destructive interference that would be had if everyone could interact concurrently. Therefore the contribution of the research in this chapter is in demonstrating that existing single-user grid-based TV interfaces have the potential to be opened up to multi-user use. There are a number of ways in which TV media systems can potentially accommodate multi-user use e.g.:

- Multi-pointer / cursor UIs
- Split-screen / screen division
- Offloading interaction onto other devices or screens
- Mediating control through proximity or attention

However, compared to existing single-user TV interfaces, these approaches have issues, for example increasing visual complexity, or requiring increased dexterity and coordination to interact effectively. Mediation of control can provide an alternative to moving away from single-user grid-based interfaces, whilst allowing for the use of new input modalities and mechanisms (e.g. mobile phones with IR support, remote applications, gestural controls). This is relevant because grid-based navigation is still used in a variety of smart TV interfaces (e.g. Android TV). Whilst multi-user interaction in grid-based interfaces could also be supported through multiple directional cursors, this too is likely to lead to confusing and destructive inputs with regard directional navigation (e.g. moving one cursor to the edge of the screen, triggering a scroll event for all users), and an increase in visual complexity. Mediation of control allows for the TV interface to remain as it is currently: with one single cursor, and navigation controlled by one user at-a-time. As an example, consider a TV which can be controlled by every smart phone in the room; mediation of control would allow users to share interaction with this single-user interface, with destructive inputs (e.g. both attempting a navigational event simultaneously) being prevented in the process.

Given the results from the existing behaviours survey and Experiment 1, the answer to Research Question 1 is that existing single-user TV interfaces, specifically those based on discrete grid-based single-cursor interaction, are suitable for multi-user use only when the constraint of "one user at-a-time" interaction with said interface is upheld.

4. SHARED USE OF THE TV

AS demonstrated in Chapter 3, the TV interface can be shared between multiple users. However, this requires that users take part in the same fundamental activity, meaning that independent use is not facilitated. Thus if one user wished to browse an EPG without interrupting others' viewing, they would typically move to a separate device such as a smartphone or tablet to perform this activity, or go analogue, for example using newspaper or magazine TV listings. Transitioning from a shared focal point to a heads-down interaction with a mobile device can be perceived as being anti-social [216]. Moreover, having the activity on a private device limits the capability of others to choose to transition to, take part in or attend to this activity. By browsing an EPG listing on a phone or tablet, for example, others are denied the capability to interact. Even viewing said device to collaborate can become difficult, if the device display is not readily physically accessible (e.g. viewers on opposite seating).

Research Question 2 asks:

> How can TVs support both shared and independent use?

Whilst there have been approaches in consumer smart TVs that aimed to support both shared and independent activity, for example employing screen division to accommodate multiple independent activities on one display (see Section 2.2.2.2), this use case suffers due to a fundamental constraint: that the TV can support only one physical view shared between its users. This Chapter examines how this constraint can be overcome, and use of the TV shared such that both collaborative and independent activity can be supported. It does so through utilizing a multi-view capable TV i.e. one which supports multiple separate physical views, thus allowing every viewer of the TV to have their view privately customized. This capability is used to enable interfaces that allow both independent and shared use of the TV, and give users the capability to vary their level of engagement in others activities, without interrupting others' usage of the TV.

This chapter describes Experiments 2 (Section 4.1) and 3 (Section 4.2) which investigate how multi-view display technology can be used to allow for both independent and shared use of a TV. Experiment 2 compares an Android-based two-user smart TV against both multi-screen and multi-view displays in a collaborative movie browsing task. Based on the findings in this study, Experiment 3 iterates on this by giving users the ability to transition between casual (viewing both views) and focused (viewing only one view) modes of usage, and dynamically set their engagement with other users' activities. This work provides a foundation for multi-user multi-view smart TVs that can support both collaborative and independent activity, and transitions between activities on a single shared TV.

4.1 EXPERIMENT 2 - MULTI-USER MULTI-VIEW TV

Given the potential of multi-view displays, the aim of this study was to design, develop and evaluate a fully functional Android-based multi-view TV. Throughout this chapter there is one important constraint, namely that only the visual component of the system would be developed, and not the audio. Enabling per-user audio whilst retaining the ability to hear and converse with others is an area of active research, with solutions ranging from bone-conductance headphones, to directional sound-beams (e.g. BoomRoom [155]) and it is reasonable to expect these systems being incorporated into future multi-view displays. With respect to design constraints, it was anticipated that the multi-view TV should provide a basic eyes-free set of behaviours by which users could transition between available virtual views without compromising in terms of distraction, aspect ratio and utilized screen area. Through this, users could gain awareness of each others' activity occuring on the multi-view TV. With respect to Research Questions, the study aimed to determine:

More specifically, the study aimed to investigate how users could gain awareness of each others' activity through a multi-view TV, with the constraint of providing a basic eyes-free set of behaviours by which users could transition between virtual views without compromising in terms of distraction, aspect ratio and utilized screen area;

RQ 2.1 To what extent do multi-view TVs improve upon single-view TVs in terms of perceived workload, usability, and ability to collaborate?

RQ 2.2 To what extent does the awareness provided through a multi-view TV compare to the optimum or desired level of awareness, given activity that is physically accessible via gaze transitions?

To answer these Research Questions, firstly a two-view (meaning two interactive virtual views), two-user (meaning the system supported two independent physical views made up of whatever was to be rendered from the virtual views) multi-view prototype was constructed, with the capability to allow two users to transition between collaborative and independent activity. An overview of this design can be seen in Figure 4.1.

Users were provided with two touch gestures (enacted via a touchpad; see Section 4.1.1) to switch between the two available virtual views. The *transition* gesture switched the user between the two available virtual views, at which point they were free to interact with the current view. The *peek* gesture allowed the user to switch to the view they were not currently interacting with for so long as they performed the gesture, at which point they would return to their current interactive view. Through these behaviours, it was hypothesized that users would be able to adequately determine their awareness of each others' activity, transitioning between independent and collaborative states, and gaining awareness of what activity their partner was performing, if they felt the need.

4.1.1 IMPLEMENTATION OF MULTI-VIEW DISPLAY

To provide users with a fully-functioning multi-view TV there was a realisation that the common approach of implementing software capable of allowing users to only perform a given task (e.g. implementing a multi-view photo browsing application, or the EPG interaction of the previous chapter) would not be representative of smart TV usage. Thus, for this prototype the aim was to develop a generalised, ecologically valid multi-view system that would give users capabilities comparable to current smart TVs, allowing them to interact with commonly used consumer applications. Given the adoption of Android into smart TVs[1], a system utilizing multiple emulated Android devices best approximated this aim. As such, instances of Genymotion[2], a high-performance x86 Android emulator running Android 4.x, were used as the underlying operating system, with each Android emulator being a separate physical view.

To present users with entirely separate views, which could be of the same virtual Android device, or different devices, depending on the users current display settings, nVidia 3D Vision display technology was used. This constituted of an active-shutter IR transmitter, coupled with an nVidia graphics card performing stereoscopic rendering at 120 Hz, 60 Hz worth of "left" eye frames, and 60 Hz worth of "right" eye frames. To provide users with independent views, "left" eye frames were to be viewed by one user, whilst "right" eye frames by another. This was achieved using Youniversal active-shutter glasses[3] which had the capability to be set into a "2D" mode where only one of the left or right frames of the 3D image was allowed through both eyes.

[1] https://www.android.com/intl/en_uk/tv/
[2] genymotion.com/
[3] xpand.me/products/youniversal-3d-glasses/

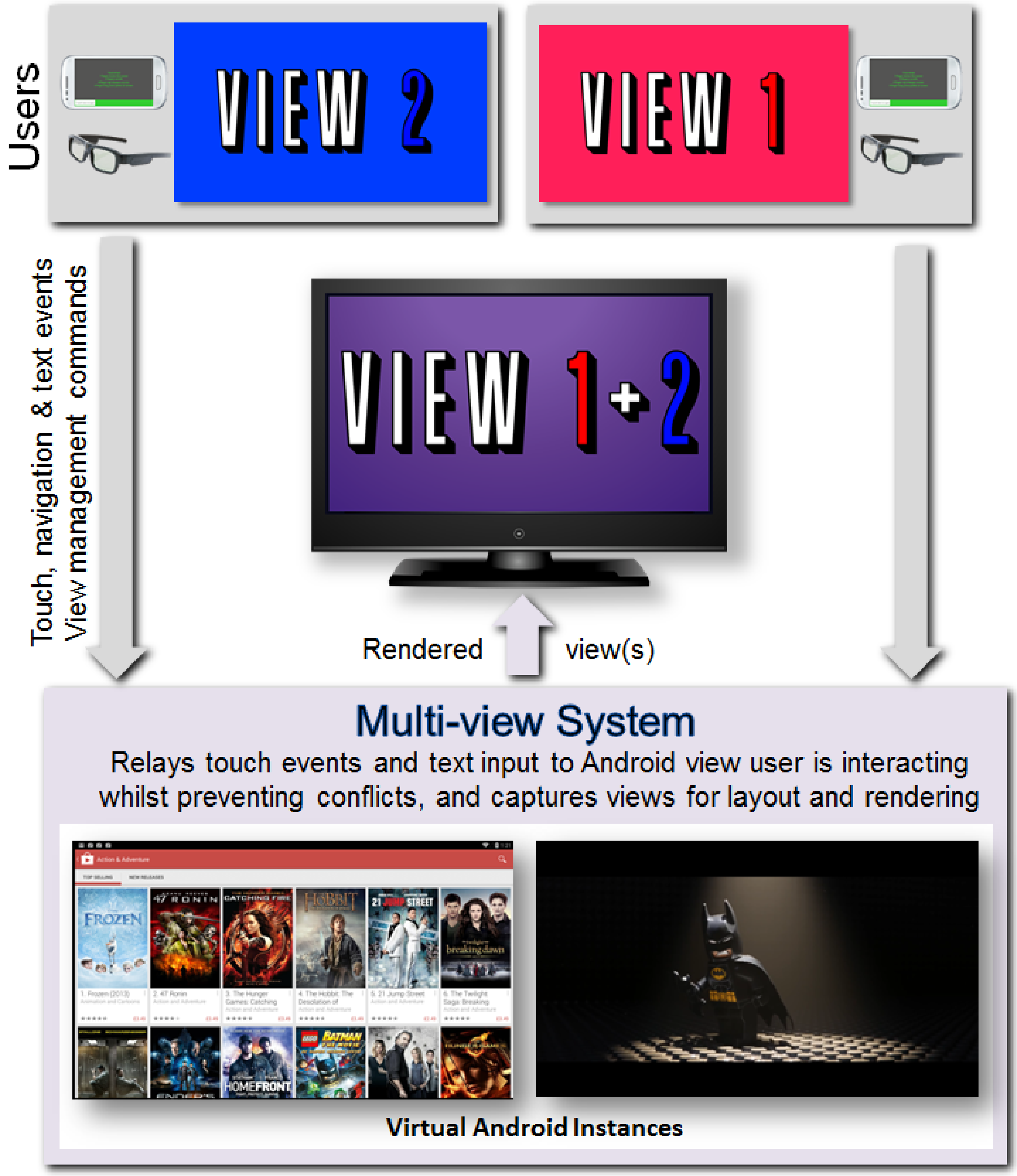


Figure 4.1: Overview of multi-view system in both studies. Here two users can have completely independent physical views (labeled View 1 and View 2) generated using two virtual Android views, with inputs routed appropriately.

The Android emulators were screen captured and rendered as a stereoscopic image, such that the left image constituted of whatever view should be presented to one user, and the right image whatever view was to be presented to the second user. In this way, two virtual views could be maintained and presented independently to two users, made up of whichever Android emulator view was required. This gave users the ability to view seperate Android emulators, or transition to the same virtual view, all without affecting their partner's physical view. To minimize crosstalk, a 24" BenQ XL2411T Display which supported nVidia LightBoost was used to deliver these images. This resulted in little to no perceptible ghosting between views; this was important as it meant that awareness could only be gained through the prescribed multi-view behaviours and mechanisms, not through inadequacies in the display technology.

To interact with the Android virtual views, Samsung S3 phones were used as touchpad remotes, rendering coloured cursors which matched the colour of the user's touchpad on whichever view they were interacting with. When occupying a view, a coloured eye would be rendered in the bottom right corner, to allow users to be aware of when they were both sharing the same view. These touchpads supported a simple set of gestures: dragging one finger moved the on-screen cursor, tapping one finger made a selection; dragging two fingers performed a scroll gesture; tapping four fingers caused a *transition* action, whilst pressing four fingers performed a *peek* action for so long as the fingers were on the touchpad. These gestures would allow for management eyes-free. Additionally the physical back, home, and application switcher buttons were mapped to the same functions in the emulator. Text input was provided via the on-screen keyboard. These interaction events were sent to a software server then routed to the appropriate Android virtual view via the Android Developer Bridge. For a video of the system in use, see [4].

4.1.2 EXPERIMENTAL DESIGN

The study design incorporated three Conditions: *(1) Single display* with one LCD display and one shared virtual Android view, as a comparative baseline for a standard smart TV (RQ 2.1); *(2) Two displays* with two LCD displays with a virtual Android view on each, enabling measurement of the default level of awareness of each others activity as users could transition between views by gaze (RQ 2.2); *(3) Multi-view display* with a single LCD display providing two independent physical views, each displaying either of two virtual Android views depending on the user's usage of the system (see Figure 4.2).

The experimental task chosen was movie browsing, a loosely coupled and ecologically valid collaborative task that commonly occurs on TVs e.g. collaborative searching for entertainment [151]. Movie browsing can be performed independently or together, but the eventual

[4]https://www.youtube.com/watch?v=VizRN0ggM9k

outcome (having to select acceptable movies to the group) necessitates collaboration. Users were instructed to browse a given set of categories of movies in the Google Play store application, with the task of selecting movies to watch together with mutual friends for the duration of each Condition. Three categories were selected for each Condition to ensure a breadth of unfamiliar movies for each Condition, with users instructed they could browse them however they saw fit. Additionally, users had the capability to watch trailers (with the instruction to moderate trailer viewing time to under a minute per trailer) and use a selection of other applications if they so wished, namely the Chrome web browser and the IMDB app. Users were tested for 15 minutes per Condition in a within-subjects design, and there were 9 pairs, 18 users in all (mean age=23.6, SD=5.5, 16 male, 2 female) recruited from University mailing lists as pairs that knew each other (e.g. friends, family etc.).

To determine the effects on users' abilities to collaborate effectively, a post-condition questionnaire was deployed, constituting of questions from previous research into collaborative displays [215, 191, 152, 125] examining perceived ability to collaborate and be aware of the activity of a partner. Workload (NASA TLX) and usability (System Usability Scale (SUS)) were also recorded, and participants were asked to rank the Conditions in order of preference.

To establish the default / optimal level of awareness of each others' activity, for the *two displays* Condition video footage of each participant was recorded and analysed, through manually annotating timestamps regarding which display the participant was looking at, if any. This annotation was conducted once only, by the experimenter alone, due to both ethical and resource constraints, given the volume of video to be annotated. Annotations were conducted one clip at-a-time, with breaks between clips, and annotation conducted in ~hour long sessions, one a day, in order to guard against errors due to fatigue or lack of concentration. These timestamps, along with logs of viewing in the multi-view display Condition, were parsed such that the viewing behaviour across Conditions could be instrumented and compared. Where applicable, Gini coefficients were calculated. These are a measure of inequality used for analysing viewing distribution in previous studies e.g. [226]; 1 denotes

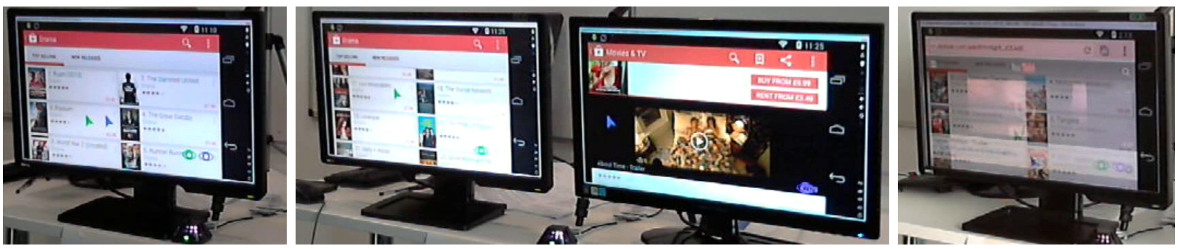


Figure 4.2: Left: Condition 1, single display with one virtual view. Middle: Condition 2, two displays, each with its own virtual view. Right: Condition 3, multi-view display when viewed without active-shutter glasses. This supports two independent physical views (and thus two users), constituting of whichever Android virtual view each user wishes to interact with.

maximum inequality i.e. $100 - 0$ or $0 - 100$, and 0 maximum equality i.e. a 50-50 distribution when dealing with two items. As use of Gini coefficients typically involves two comparison points in this chapter, for both Experiments directed Gini coefficients are used where applicable, whereby the direction of inequality is encoded such that 100-0 would resolve to 1, whilst $0 - 100$ would resolve to -1. For further details see Section A.3. See Appendix E for experimental materials (question set and plain language statement given to participants).

4.1.3 RESULTS

Where appropriate a repeated-measures ANOVA with *post hoc* Tukey's test or a Friedman test with *post-hoc* Bonferroni corrected Wilcoxons was performed, green indicates $p < 0.05$, as described in Appendix A. Significant differences were found between Condition 1 (single display) and Conditions 2 (two displays) and 3 (multi-view display). Conditions 2 and 3 were superior in terms of capability to collaborate (e.g. WS-1, MO-1), ability to work independently (WS-2), and workload/usability (see Table 4.1). However, there were no significant differences between Conditions 2 and 3, with Condition 2 typically having only moderately higher mean scores.

User rankings (see Figure 4.3) again showed significant differences between Condition 1 and Conditions 2/3, with both conditions ranked better. There was no significant difference between the mean rankings of Conditions 2 and 3.

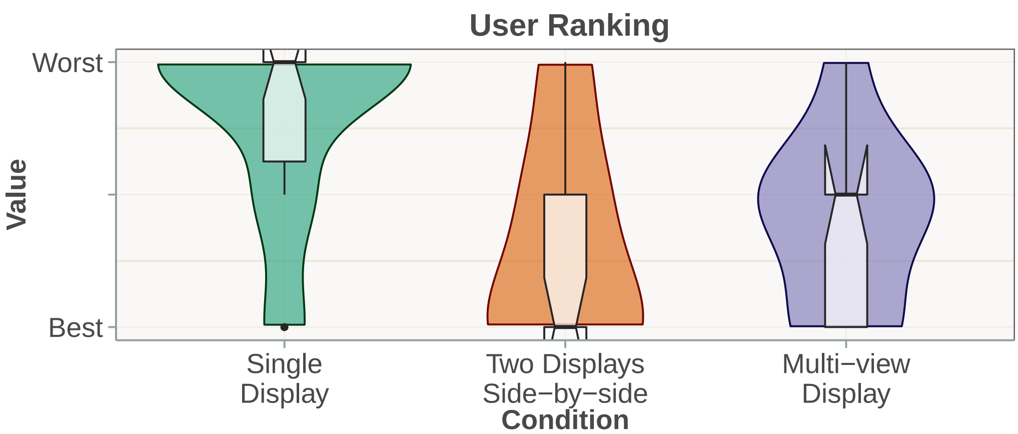


Figure 4.3: User ranking – Friedman test $\chi^2(2) = 10.3, p < 0.01$, *post hoc* Bonferroni corrected Wilcoxon test showed differences between 1-2 and 1-3

4.1.3.1 VIEWING AND INTERACTION

Examining the viewing patterns and behaviours exhibited in Conditions 2 and 3, significant differences were found in terms of viewing behaviour (see Table 4.2 and Figure 4.4). This

Question	Condition: 1: Single Display	Condition: 2: Two Displays	Condition: 3: Multi-view Display	Friedman Test	Wilcoxon *Post-hoc* ($p < 0.05$)
WS-1: We were able to collaborate effectively	3.11 (1.81)	4.94(1.21)	5.00 (0.77)	$\chi^2(2) = 16.0, p < 0.01$	1-2, 1-3
WS-2: We were able to work independently to complete the task	1.94(1.47)	5.67(0.49)	5.33(0.49)	$\chi^2(2) = 31.5, p < 0.01$	1-2, 1-3
WS-3: It was easy to discuss the information we found	4.39 (1.65)	5.50 (0.62)	5.39 (0.78)	$\chi^2(2) = 7.61, p < 0.05$	None
WS-4: We were able to work together to complete the task	3.94 (1.70)	5.28 (1.07)	4.78 (1.44)	$\chi^2(2) = 7.4, p < 0.05$	1-2
WS-5: I was able to actively participate in completing the task	3.83 (1.425)	5.61 (0.50)	5.33 (0.77)	$\chi^2(2) = 21.4, p < 0.01$	1-2, 1-3
MO-1: How well did the system support collaboration?	2.56 (1.72)	4.72 (1.18)	4.78 (0.88)	$\chi^2(2) = 17.2, p < 0.01$	1-2, 1-3
MO-2: How well did the system support you to share particular information with your partner?	3.94 (2.01)	4.61 (1.75)	5.17 (0.92)	$\chi^2(2) = 1.82, p = 0.4$	NA
MO-3: I was able to tell when my partner was looking at what I was browsing?	4.89 (1.60)	5.17 (0.92)	5.39 (0.61)	$\chi^2(2) = 0.383, p = 0.83$	NA
MO-4: How well did the system support you to see/review what your partner was talking about?	4.83 (1.25)	5.33 (0.69)	5.50 (0.62)	$\chi^2(2) = 5.57, p = 0.06$	NA
WE-1: The system was helpful in completing the given task	3.11 (1.68)	5.06 (0.94)	5.06 (0.87)	$\chi^2(2) = 20.8, p < 0.01$	1-2, 1-3
WE-2: I was aware of what my partner was doing	5.39 (0.85)	5.00 (1.33)	4.67 (0.97)	$\chi^2(2) = 9.48, p < 0.01$	None
PE-1: My partner was aware of what I was doing	5.28(0.96)	5.06 (1.06)	4.56 (1.10)	$\chi^2(2) = 9.49, p < 0.01$	None
TLX: Overall Workload (ANOVA)	38.50 (24.70)	19.40 (16.00)	22.20 (15.40)	$\chi^2(2) = 18.86, p < 0.01$	1-2, 1-3
SUS: System Usability Scale (ANOVA)	58.10 (22.20)	83.30 (14.30)	78.90 (13.80)	$\chi^2(2) = 20.62, p < 0.01$	1-2, 1-3

Table 4.1: Questions from [138]: (WS) WebSurface[215], (MO) Mobisurf[191], (WE) WeSearch[152], (PE) Permulin[125]. Questions were 7-point Likert scale (results range from 0-6, higher is better). TLX is from 0 (lowest) to 100 (highest), SUS is from 0 (worst) to 100 (best). Means with standard deviations are presented across Conditions. A Friedman test was conducted with *post hoc* Bonferroni corrected Wilcoxon tests, unless otherwise labeled (ANOVA) in which case a repeated measures ANOVA with *post hoc* Tukey's test was performed.

difference is visualized in Figure 4.4, where Condition 2 ~50% of overall viewing and ~90% of viewing instances were accounted for in viewing instances which lasted under 10 seconds; in comparison, Condition 3 demonstrates that users relied on much longer views, showing a clear difference in behaviour.

	Condition		
	2	3	RM-Anova
Mean Duration of Views (secs)	3.39 (3.51)	40.64 (37.40)	$\chi^2(1) = 16.6, p < 0.01$
Gini: Interaction	0.839 (0.27)	0.641 (0.34)	$\chi^2(1) = 3.75, p = 0.053$
Gini: Viewing	0.394 (0.233)	0.447 (0.306)	$\chi^2(1) = 0.356, p = 0.55$

Table 4.2: Mean (SD) Viewing and Interaction comparison between Conditions 2 and 3. Gini coefficients show equality regarding how likely users were to view or interact with either Android view, 1 is maximum inequality, 0 is maximum equality.

	Viewing Mechanism		
	Transition	Peek	RM-Anova
Mean Total Viewing (SD)	566.8 (36.4)	32.9 (36.4)	$\chi^2(1) = 146, p < 0.01$
Mean Duration of Views (SD)	45.98 (36.3)	8.22 (18.3)	$\chi^2(1) = 13.5, p < 0.01$

Table 4.3: Mean (SD) viewing for Condition 3 (multi-view display) broken down by whether a transition or peek resulted in said view.

In terms of how this viewing was accomplished in the multi-view display, Table 4.3 demonstrates that the *transition* behaviour was utilized for the majority of this viewing, with the *peek* gesture accounting for only ~5% (~32 seconds) worth of viewing on average. Given that the peek gesture was intended to allow quick and casual viewing of a partners activity, the lack of usage evidenced in Figure 4.4 suggests that this gesture, whilst utilized, was not sufficient for providing casual awareness.

In terms of the distribution of viewing between the displays/virtual views, the Gini coefficient of viewing (see Table 4.2) suggests there was little difference between Conditions 2 and 3. However, if viewing is broken down on the assumption that the physical / virtual view that the user started with was the view they would own or use for the majority of the time, it can be seen that this assumption holds for Condition 2, but not for Condition 3 (see Figure 4.5), with a small number of participants either sharing use of both virtual views more evenly, or entirely switching which display they used as “their” space. This suggests that the multi-view display diminishes the sense of ownership of a space.

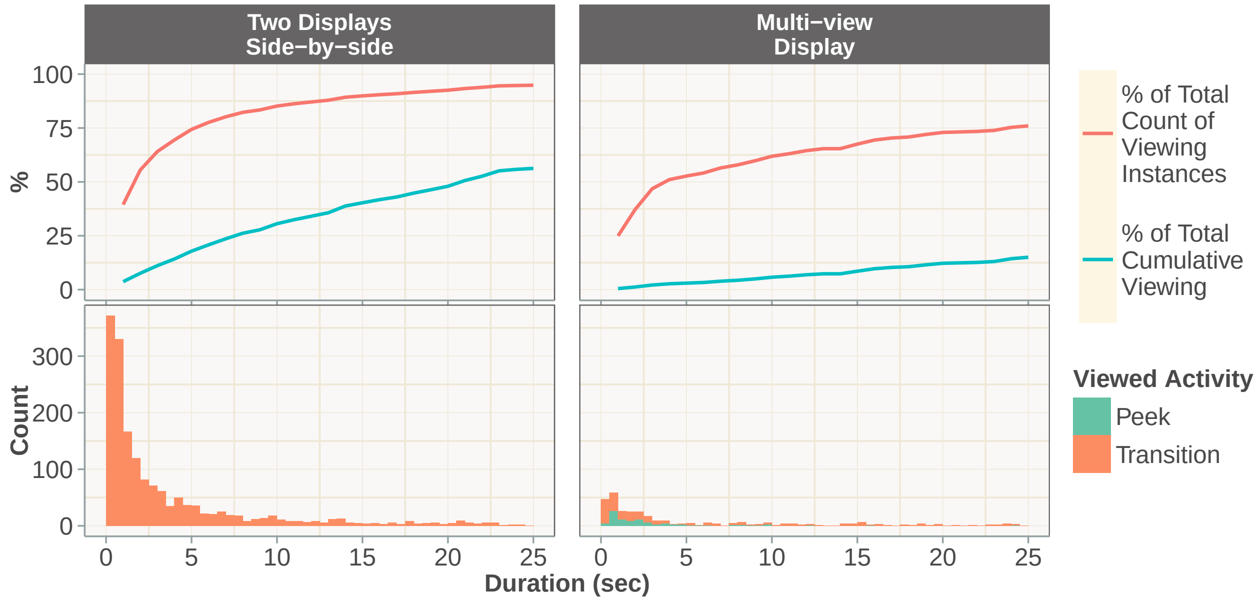


Figure 4.4: Individual viewing behaviour across participants. Bottom: Histogram (0.5 second bins) counting number of instances of viewing at a given duration. Top: Graph presenting percentage of overall cumulative viewing and percentage of overall number of viewing instances.

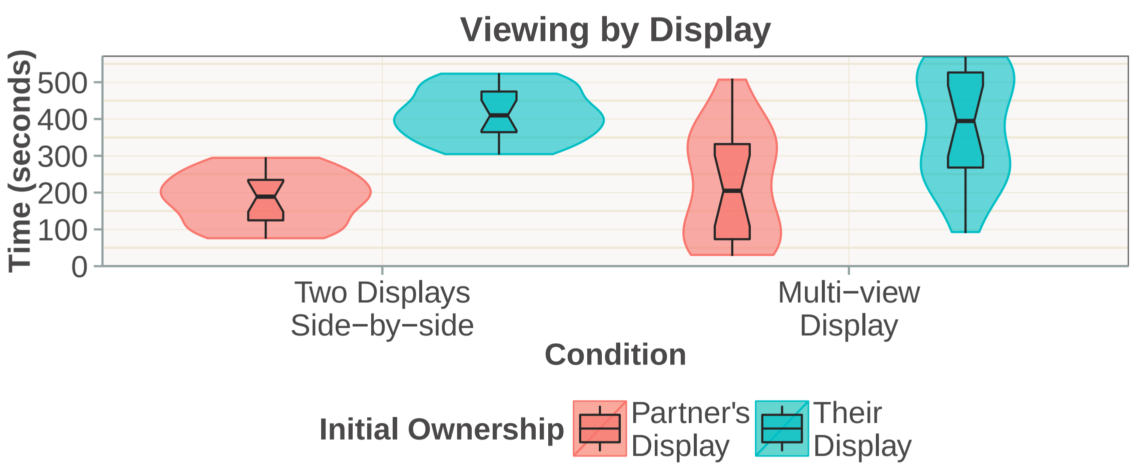


Figure 4.5: A two-way repeated measures ANOVA found a significant effect on display type (theirs / not theirs) $F(1, 34) = 49.7, p < 0.01$ but not Condition $F(1, 17) = 0.0, p = 0.98$. Additionally there was no interaction effect.

With respect to how likely users were to view or interact with (i.e. perform touchpad or textual actions on) either virtual view (see Table 4.2) there were no significant differences between Conditions 2 and 3. There was a bias toward equality with respect to interaction with the multi-view display, however this was likely due to the fact that once a user performed a transition in Condition 3, they were free to interact with the view they had transitioned to. In Condition 2, these transitions were typically managed by gaze, thus users would have to explicitly perform the transition gesture to then interact with this view. This suggests an interesting benefit of multi-view displays when coupled with touchpad remote controls: inputs can always be routed to the view the user is attending to. For a MDG system to accomplish this would require gaze tracking, a different input modality or additional effort on behalf of the user to manage which display they were interacting with, effort which the results of Condition 2 suggest users were unlikely to undertake.

4.1.3.2 CO-VIEWING

There was no significant difference between Conditions 2 and 3 with respect to the total amount of co-viewing (i.e. viewing of the same virtual view in Condition 3, or physical view in Condition 2 - Condition 1 was omitted as the entire duration constituted co-viewing) as seen in Figure 4.6. However, there was a significant difference in the mean duration of co-viewing instances between Conditions 2 and 3 ($\chi^2(1) = 4.51, p < 0.05$), with viewing instances lasting for approximately 3.1 seconds (SD 8.3) in Condition 2, compared to 13.6 seconds (SD 28.8) in Condition 3. This is influenced by the glance-based behaviour demonstrated previously, with co-viewing frequently cut short by glances back and forth between the available physical displays.

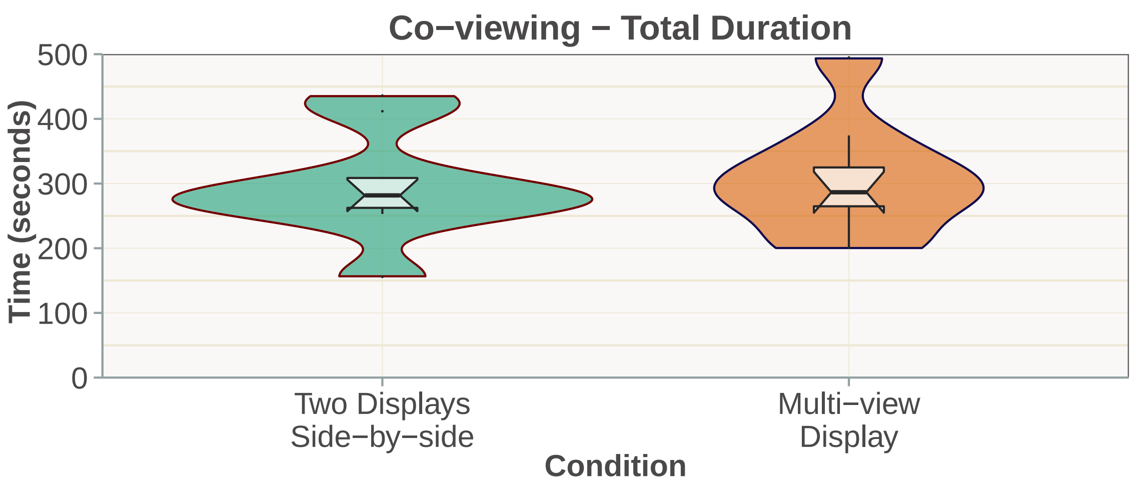


Figure 4.6: Total duration spent viewing the same virtual or physical view. $\chi^2(1) = 0.069, p = 0.79$.

4.1.3.3 SHARED AUDIO SPACE

With respect to the acceptability of using a shared audio space, Figure 4.7 suggests that being able to hear audio coming from both displays was marginally less acceptable in the multi-view Condition compared to the two physical displays of Condition 2, however the difference was not statistically significant.

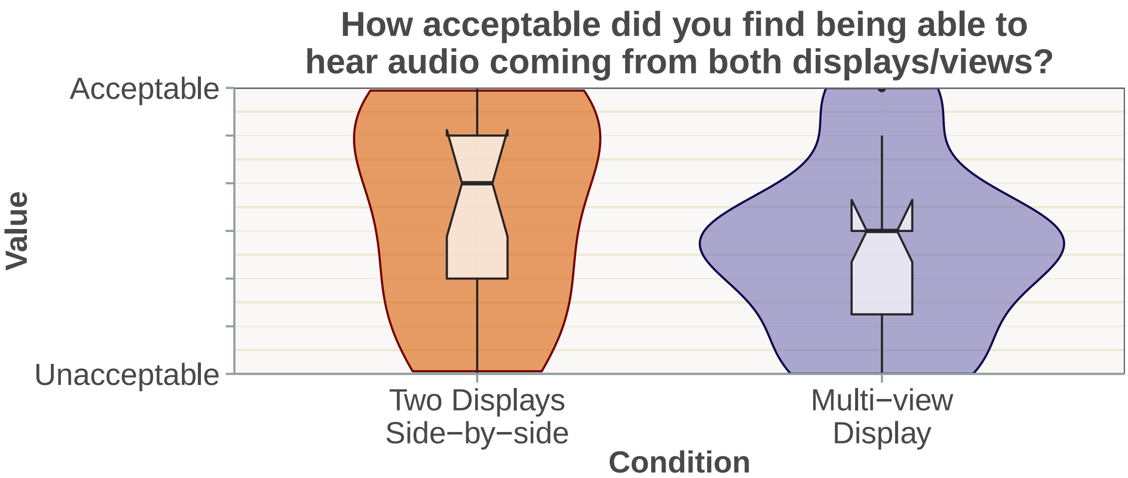


Figure 4.7: Condition 2 mean=3.50 SD=2.15; Condition 3 mean=2.61, SD=1.85, $\chi^2(1) = 2.886, p = 0.09$

4.1.4 DISCUSSION OF EXPERIMENT 2

The results demonstrated that a multi-view TV is preferable to a single-view TV (RQ 2.1), which is not entirely surprising. As much as interfaces can be designed to support multi-user use on a standard TV, the bottleneck of one physical view inevitably negatively affects the capability to share use of such a display. The comparison between the multi-view display and the two physical displays did, however, demonstrate some marked differences not in how well users perceived their ability to collaborate or gain awareness of each others activity, but in how this awareness was accomplished (RQ 2.2). The two physical displays in Condition 2 were used to facilitate a casual and continual awareness of the activity of the other participant, through a multitude of shorter glances at each display. In contrast, the multi-view condition featured much longer views of each virtual view. An attempt was made to facilitate casual awareness through the *peek* gesture, however this difference in viewing behaviour suggests that casual awareness is more readily accomplished by gaze.

Whilst having two displays in close proximity was marginally preferable to multi-view, it could also be argued that a sufficiently large display might thus employ screen-division in much the same way that this Condition functioned. However, it is unlikely that a sufficiently large screen-divided single display, or a multi-display configuration would be acceptable in the home, for example with respect to size and the issue of needlessly attending to potentially visually distracting activities. Thus these results suggest that a multi-user multi-view TV must accommodate for casual awareness, in order to facilitate the preferred behaviours of users as instrumented in the two-display Condition.

4.2 EXPERIMENT 3 - MULTI-VIEW CASUAL AWARENESS

The results of Experiment 2 raised a significant question. If perceived awareness and ability to collaborate was not significantly different between the two-display and multi-view conditions, but the way in which this awareness was accomplished was (with much shorter glances between displays), should an attempt be made to enable this more casual, continual gaze-based awareness, and how? Incorporating continual and casual awareness necessitates a compromise with respect to distraction due to other user's activity, as some aspect of the user's physical view must be used to provide this awareness. This goes against one of the primary aims of the initial multi-view study, which was to develop a set of behaviours that would allow for management of multiple views whilst not compromising the user's current physical view in terms of distraction, aspect ratio and utilized screen. To study this, a system was designed to answer the following questions:

RQ 2.3 How much of their physical view are users willing to sacrifice to gain a casual awareness of other virtual views?

RQ 2.4 Given the ability to transition between a casual awareness mode and a fullscreen mode, how would users appropriate such a system: would they rely on only one mode, or use both, and if so to what degree would they use both modes?

Two additions were made to the prototype multi-view TV system, applying the concept of the casual–focused continuum [175] to awareness. The first was to give users the ability to vary their engagement with others by controlling how much of their personal physical view was given up to awareness of what is happening in other virtual views (see Figure 4.8). This was accomplished through the use of a slider on the touchpad (see Figure 4.9). At its extremes, it would devote the majority of the user's physical view to either to the virtual view the user was interacting with, or the other available virtual view; as the slider moves to the center of the touchpad, the user's physical view would begin to be split evenly between both virtual views.

It was anticipated that this mechanism could encompass a variety of behaviours, from selecting an appropriate ratio between the virtual views as a one-off, to repeatedly employing

Figure 4.8: Example of two users in the dynamic split-screen mode, with different levels of engagement with each others activity. The user's currently interactive virtual view is always on the right of the physical view.

the slider to dynamically change the ratio between the virtual views as and when required. This, for example, would allow users to be aware of a trailer their partner might be watching in the other virtual view. Through this, any norms with respect to how much of the physical view users were willing to give up for casual awareness could be established. It is important to note that the aspect ratio of the content being viewed was preserved at all times, thus resulting in portions of the screen remaining unused, as can be seen in Figure 4.9.

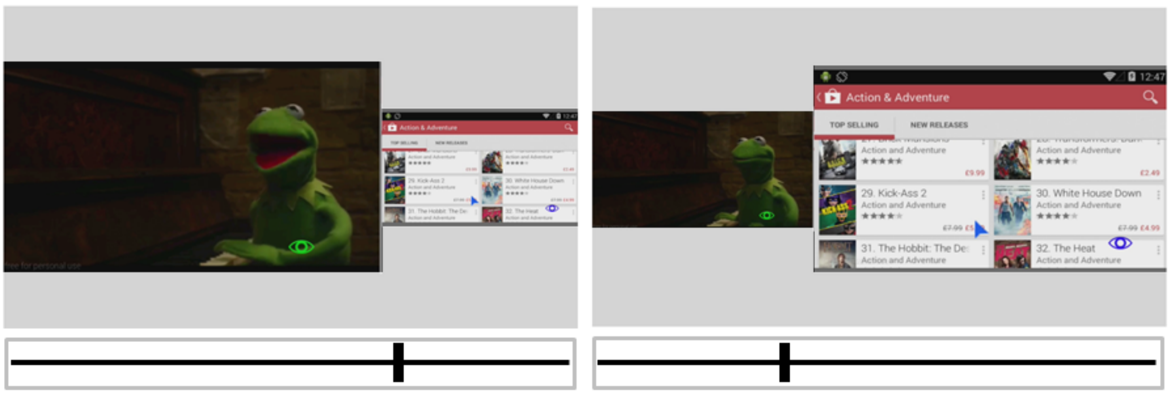


Figure 4.9: Example of the dynamic split-screen slider design. Here a user's physical view (shaded grey) is being transformed Left: from a bias toward the currently non-interactive virtual view on the left; Right: to a new bias toward the interactive virtual view on the right.

The second addition was the ability to transition between this casual awareness mode and the fullscreen / fully-focused awareness mode that was the multi-view display in the previous study. A 3-finger tap gesture allowed users to switch between the casual awareness mode, utilizing whatever screen ratio it was previously set at, and the fullscreen awareness mode.

In both modes, the *transition* and *peek* behaviours functioned as before; in casual awareness mode, these actions resulted in the two virtual views swapping positions for that user.

4.2.1 IMPLEMENTATION AND EXPERIMENTAL DESIGN

The implementation was the same as Experiment 2, aside from the changes to allow for casual awareness. Transitions between modes, use of the slider and transitions between views were all animated, with changes to the slider affecting the rendering in real-time. Users could interact with only one virtual view at a time; this interactive view was always to the right of the user's screen, and signified with a grey border. For a video of the system in use, see [5].

There were three Conditions: *(1) Multi-view display* which was the fullscreen multi-view display from the previous study, serving as a baseline for new iterations of the multi-view design; *(2) Dynamic Split-Screen Multi-view* which was a display that provided only the casual awareness slider functionality; and *(3) Selective Multi-view* which provided users with the ability to switch between the modes from Conditions 1 and 2 using a 3-finger tap.

As the aims of this study were primarily investigating how users would appropriate a system which supported both casual and fullscreen awareness behaviours, the ordering of the Conditions was only partially counter-balanced with respect to Conditions 1 and 2, with Condition 3 always occurring last. This was done so that users received significant training with respect to using the fullscreen and casual awareness systems before using the dual-mode system in Condition 3. As such, they could be expected to make an informed choice regarding how they used the available functionality to interact with their partner.

With respect to measures, all transitions between views and modes were logged to see both users default behaviour in each condition, and how they appropriated the selective multi-view system. The same task design and post-Condition questionnaires were utilized as from the previous study, with the addition of asking users how distracting they found their partner's activity and how in control they felt regarding awareness of their partner's activity. Users had access to the same set of applications as in the previous multi-view study. There were 7 pairs of participants, 14 users in all (mean age=26.4, SD=3.3, 14 male) that again knew each other (friends, family etc.), recruited from University mailing lists. See Appendix F for experimental materials (question set and plain language statement given to participants).

[5] https://www.youtube.com/watch?v=VizRN0ggM9k

4.2.2 RESULTS

4.2.2.1 QUESTIONNAIRE

Unlike in Experiment 2, there were no significant differences in the questionnaire responses in terms of ability to collaborate, awareness, distraction, usability and workload, as can be seen in Table 4.4. However, mean scores for the fullscreen Condition (1) were typically poorer than Conditions 2 and 3. This suggests that the casual awareness functionality provided only a marginal improvement upon the awareness-seeking behaviours implemented in the fullscreen Condition.

The exception to this trend was in the distraction questions (see Figure 4.10) where mean distraction was higher in Conditions 2 and 3, however again not statistically significantly so. This suggests that in being able to moderate their awareness, users could in turn moderate their level of distraction.

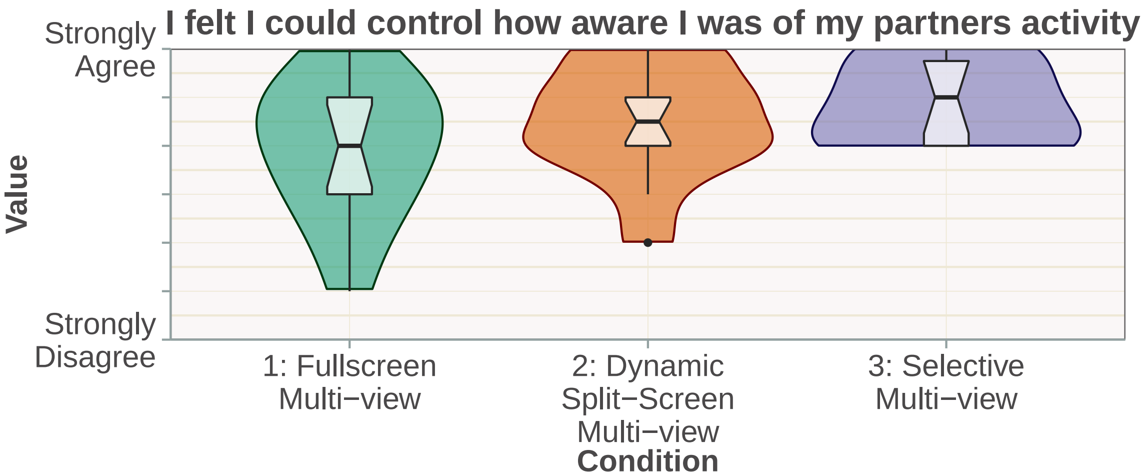


Figure 4.10: Dist-2: “I felt I could control how aware I was of my partners activity”. Higher is better. Boxplots of IQR (25th, 50th, 75th quartiles) shown. $\chi^2(2) = 2.05, p = 0.36$

4.2.2.2 RANKINGS AND VIEWING

There were no significant differences with respect to user rankings (see Figure 4.11). However, there was a somewhat dichotomous split between users preferring either the selective mode or the fullscreen mode, biased toward the selective mode of Condition 3. Similarly, with respect to the proportion of viewing and interaction between the virtual views, there were no significant differences (see Table 4.5).

Question	Condition 1	Condition 2	Condition 3	Friedman Test
WS-1: We were able to collaborate effectively	4.57 (0.938)	4.93 (0.997)	4.86 (1.027)	$\chi^2(2) = 1.51, p = 0.47$
WS-2: We were able to work independently to complete the task	4.57 (1.70)	4.71 (1.44)	4.71 (1.20)	$\chi^2(2) = 0.07, p = 0.96$
WS-3: It was easy to discuss the information we found	4.64 (0.75)	5.07 (0.62)	5.00 (1.11)	$\chi^2(2) = 4.9, p = 0.09$
WS-4: We were able to work together to complete the task	4.57 (1.02)	4.86 (0.66)	4.79 (1.05)	$\chi^2(2) = 0.75, p = 0.69$
WS-5: I was able to actively participate in completing the task	4.71 (1.069)	4.86 (0.86)	5.00 (1.11)	$\chi^2(2) = 1.36, p = 0.51$
MO-1: How well did the system support collaboration?	4.14 (1.46)	4.64 (1.40)	5.07 (0.92)	$\chi^2(2) = 3.5, p = 0.17$
MO-2: How well did the system support you to share particular information with your partner?	4.21 (1.05)	4.36 (1.39)	5.00 (0.78)	$\chi^2(2) = 4.06, p = 0.13$
MO-3: I was able to tell when my partner was looking at what I was browsing?	4.86 (0.663)	4.71 (1.38)	4.71 (0.83)	$\chi^2(2) = 0.33, p = 0.85$
MO-4: How well did the system support you to see/review what your partner was talking about?	4.64 (0.75)	5.14 (0.77)	5.00 (0.68)	$\chi^2(2) = 2.18, p = 0.34$
WE-1: The system was helpful in completing the given task	4.21 (0.70)	4.64 (0.93)	4.79 (0.70)	$\chi^2(2) = 4.34, p = 0.11$
WE-2: I was aware of what my partner was doing	4.07 (1.14)	4.86 (0.77)	4.50 (1.09)	$\chi^2(2) = 2.85, p = 0.24$
PE-1: My partner was aware of what I was doing	4.43 (1.16)	4.71 (0.73)	4.50 (1.092)	$\chi^2(2) = 0.438, p = 0.80$
DIST-1: I found my partners activity distracting	2.29 (1.90)	2.36 (1.86)	1.50 (1.09)	$\chi^2(2) = 2.46, p = 0.29$
DIST-2: I felt I could control how aware I was of my partners' activity	3.93 (1.385)	4.50 (1.16)	4.86 (0.86)	$\chi^2(2) = 2.05, p = 0.36$
TLX: Overall Workload (ANOVA)	29.5 (16.7)	25.0 (17.3)	26.1 (19.1)	$\chi^2(2) = 1.73, p = 0.42$
SUS: System Usability Scale (ANOVA)	67.3 (15.0)	69.8 (15.8)	69.5 (17.3)	$\chi^2(2) = 0.27, p = 0.87$

Table 4.4: Questions derived from previous studies. WS: WebSurface[215], MO: Mobisurf[191], WE: WeSearch[152], PE: Permulin [125]. Questions were 7-point Likert scale (results range from 0-6, higher is better). TLX is from 0 (lowest) to 100 (highest), SUS is from 0 (worst) to 100 (best). Means with standard deviations are presented across Conditions. A Friedman test was conducted with *post hoc* Bonferroni corrected Wilcoxon tests, unless otherwise labeled (ANOVA) in which case a repeated measures ANOVA with *post hoc* Tukey's test was performed.

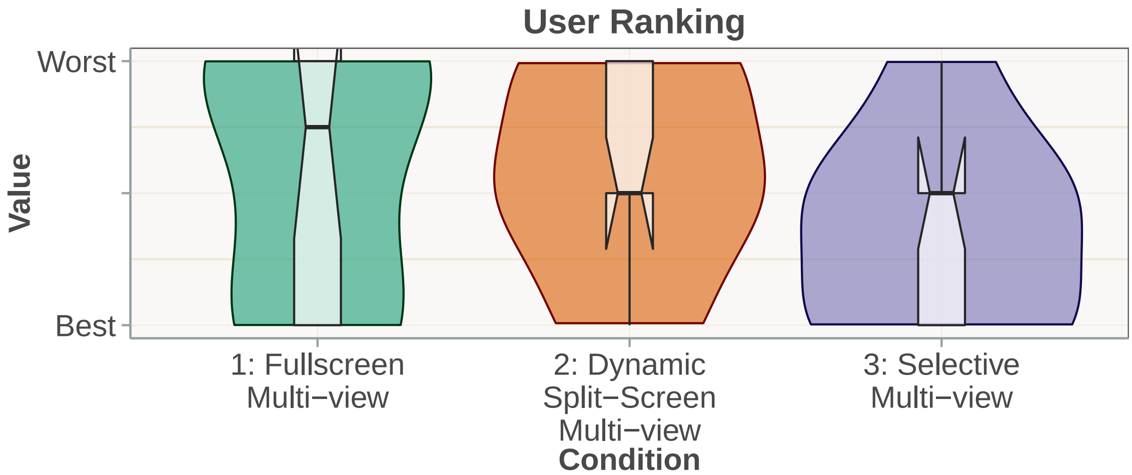


Figure 4.11: User ranking (lower is better) ordered by mean ranking - Friedman test $\chi^2(2) = 1.71, p = 0.42$.

	Condition			RM-Anova
	1	2	3	
Interaction	0.73 (0.29)	0.65 (0.29)	0.75 (0.35)	$\chi^2(2) = 1.39, p = 0.5$
Viewing	0.47 (0.25)	0.57 (0.29)	0.55 (0.32)	$\chi^2(1) = 1.39, p = 0.5$

Table 4.5: Mean (SD) Gini coefficients for viewing and interaction. Gini coefficients show how likely users were to view or interact with virtual view. 1 is maximum inequality, 0 is maximum equality.

4.2.2.3 CASUAL VS. FULLSCREEN AWARENESS

Figure 4.12 details how the usage of the selective multi-view system compared to the comparative baselines of Conditions 1 and 2. There is a relatively even split between behaviour usage in the selective multi-view system, with every capability, aside from the peek gesture, was utilized to a similar degree. The most utilized function was the gesture for switching between fullscreen and dynamic modes. Transitions between virtual views occurred in both modes, however occurred less frequently in the dynamic mode, supplanted by use of the slider for enacting changes in screen ratio.

Indeed users appeared to split their viewing between the Dynamic and Fullscreen modes relatively evenly, as evidenced in Table 4.6. In examining this split per user in Figure 4.13, it can be seen that the majority of users split their viewing time between modes equally. However, there were 3 users who favoured fullscreen mode and 3 more who almost entirely

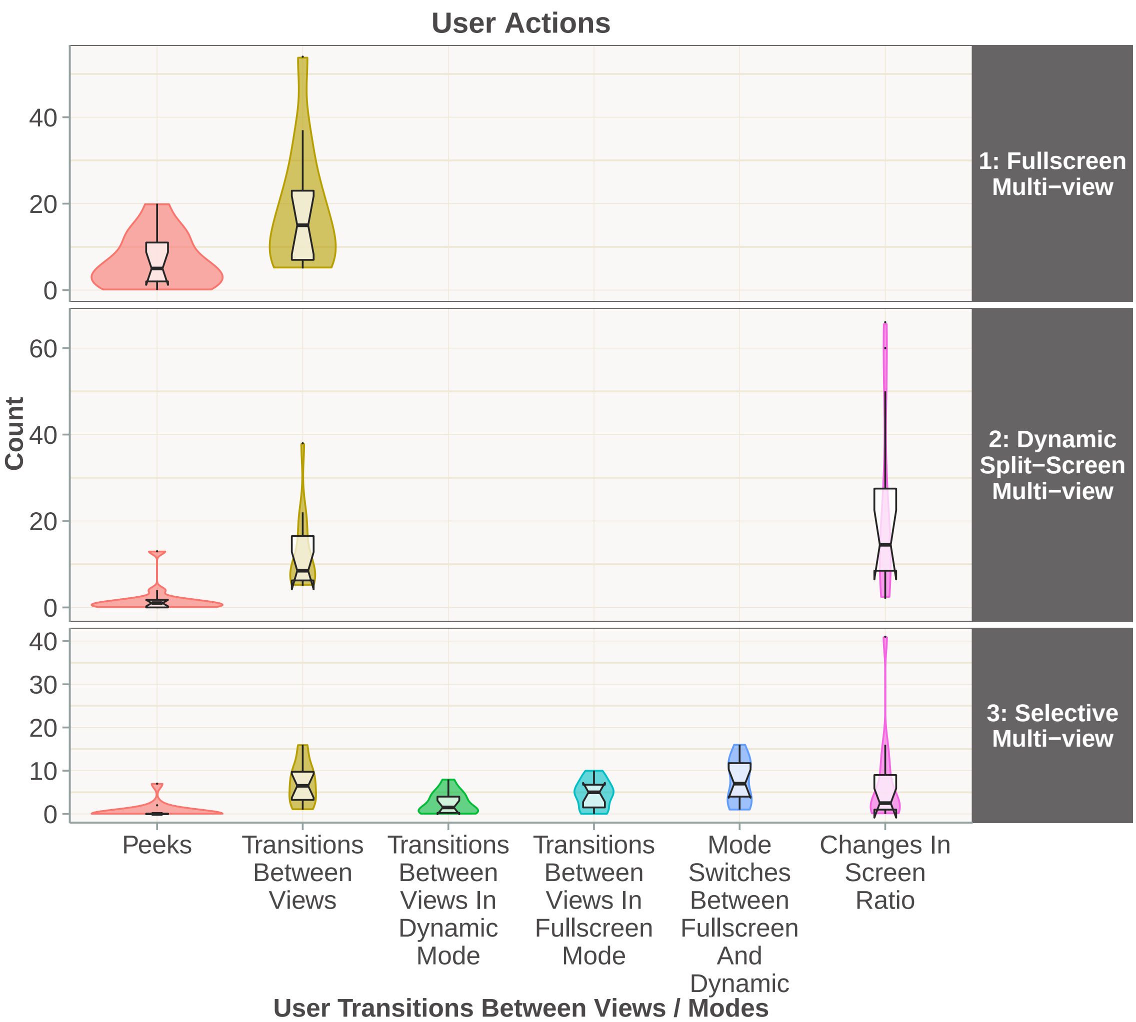


Figure 4.12: Display management actions available to users: peeks (a non interactive look), transitions between views (moving between virtual views), changes in screen ratio (a slider manipulation), and mode switches between fullscreen and dynamic states.)

favoured fullscreen mode.

	Viewing Mechanism		RM-Anova
	Dynamic Mode	Fullscreen Mode	
Mean Total Viewing (SD)	206.0 (212.0)	274.0 (212.0)	$\chi^2(1) = 2.23, p = 0.136$
Mean Duration of Views (SD)	26.6 (33.3)	30.5 (34.2)	$\chi^2(1) = 0.291, p = 0.589$

Table 4.6: Viewing for Selective Multi-view display, broken down by whether the display was in Dynamic or Fullscreen mode.

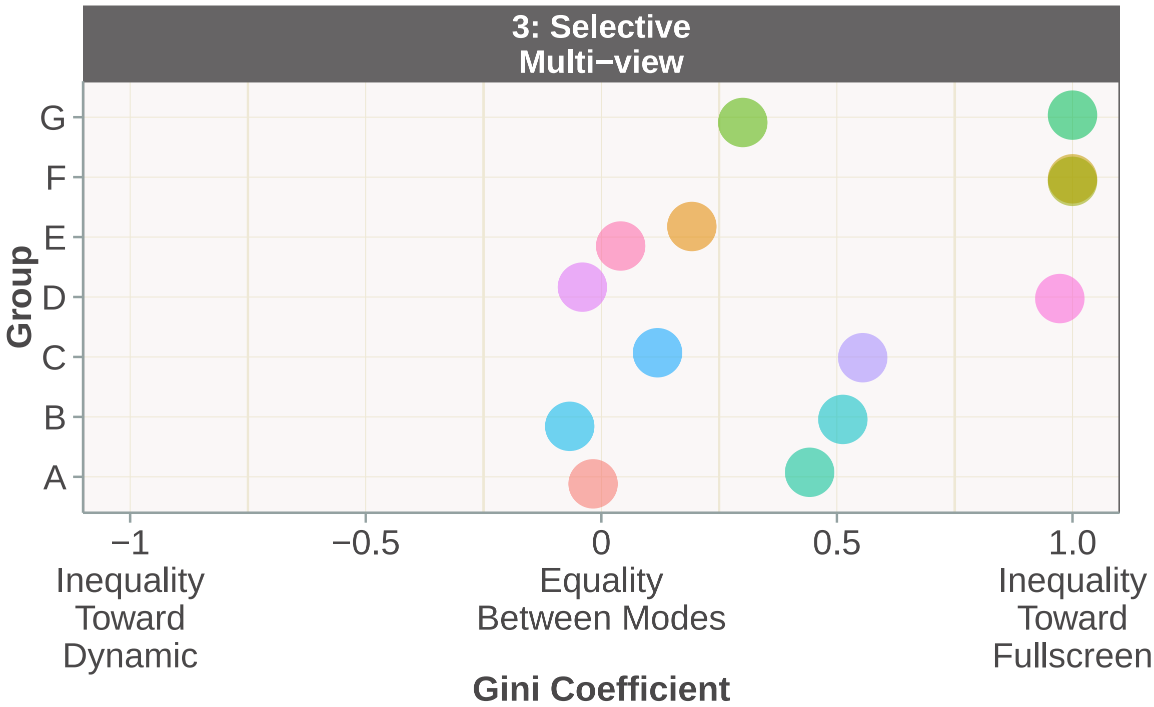


Figure 4.13: Directed Gini coefficient viewing in Dynamic and Fullscreen modes by group and participant (coloured) for Selective Multi-view. As an example, -1 indicates complete inequality toward the Dynamic mode, meaning users spent the entire duration in that mode. Jitter was added to Group axis to allow overlapping pairs to be differentiated.

4.2.2.4 USAGE OF CASUAL AWARENESS MODE

Figure 4.14 visualizes the usage of the slider bar to show how much of the display the user was willing to dedicate to casual awareness during the course of the Conditions. In Condition 2, two clear peaks can be seen, meaning that users were typically moving between using ~8% and ~31% of the width of the display for casual awareness. In Condition 3, there was a much wider variety of usage, with peaks at approximately 7%, 20%, 43%, 67% and 95%.

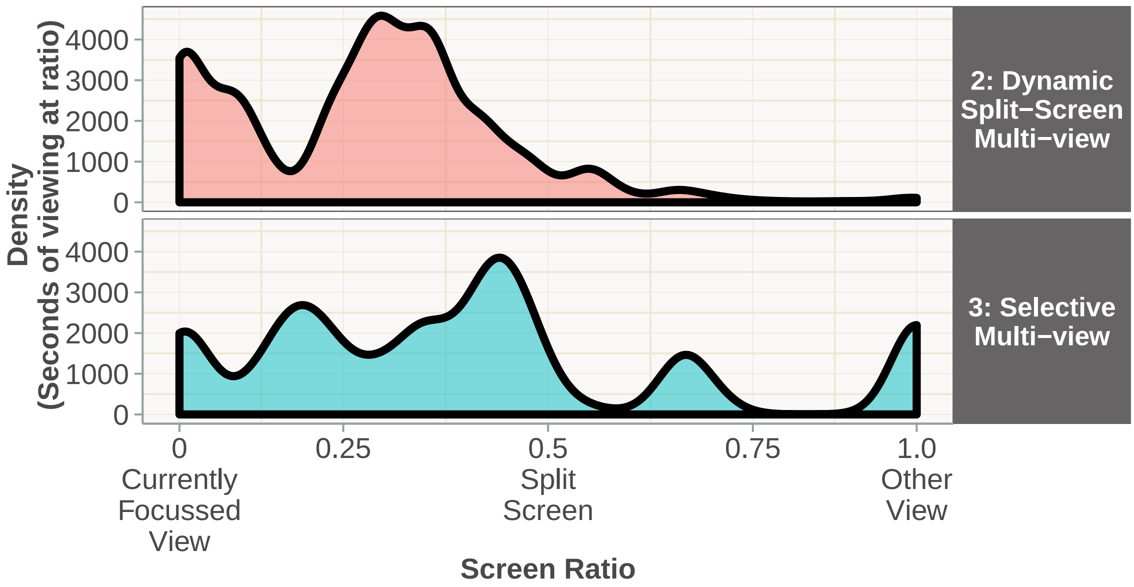


Figure 4.14: Kernel density plot of probability of distribution of slider values, determining the ratio by which the two virtual views are displayed. Left is biased toward the view the user is interacting with, right is biased toward the other available view, typically used by their partner. Condition 2 peaks at approximately $8\%, 31\%$; Condition 3 at approximately $7\%, 20\%, 43\%, 67\%, 95\%$. An ANOVA was performed, finding no significant difference between Conditions 2 and 3 ($\chi^2(1) = 3.6, p = 0.058$). (smoothing adjustment=2.5)

4.2.2.5 QUALITATIVE FEEDBACK

After the final Condition participants were asked open-ended questions regarding whether they tended to use both the dynamic and fullscreen modes or switch between them, and what prompted this switching. *G:* denotes which group the participants belonged to, from A to G and where possible participants are labeled separately, with lines separating responses from different groups. Relevant quotes are presented both from topics frequently occurring in the interviews (3 or more mentions) and novel insights.

Nine users reported switching to fullscreen mode for the viewing of trailers e.g.:

> “What I found was when I was watching a trailer I would use the fullscreen mode, when I’m browsing I definitely preferred having a split screen... I think it’s because if I’m watching a video I’d probably focus on the video rather than what the other person is doing” *G:A P1*
> “I would like to just have the other person’s... screen minimized on the side but if I want to watch something I would also need the fullscreen mode obviously” *G:A P2*

> “The overview mode was mostly what I used for browsing... then I switched to fullscreen mode for the trailer, then you can go back again when your back to the browsing part, which I thought was useful” *G:D, P1*
> “I never thought I would actually use the fullscreen one but when you’re watching an actual video that was fullscreen it didn’t make sense to lose part of the display just to have this redundant overview window when I’m switching to watch his anyway” *G:D P2*

However, this was not an exclusive activity, with six users also reporting instances of using the overview mode for watching trailers whilst they continued to interact e.g.:

> “I also tend to use the fullscreen view, but I would use the two screen views when I wanted to peek at a trailer” *G:C*

> “If there were trailers being played it was nice to be able to see what I was doing whilst also watching the trailer at the side” *G:E P1*
> “The same for me yeah, so you had your fullscreen when you were doing your own individual thing, and if there’s something relevant to both which didn’t need your direct attention, so like a trailer, then yeah you could switch over” *G:E P2*

Four users mentioned using the overview mode for browsing content e.g.:

> “I had the splitscreen on but a bit bigger than the smaller screen so the corner of my eye could see what he was doing, so I kind of swap over when we’re talking about the same thing then I’d still have a view in the corner... it meant if we were talking about something I could quickly glance over and click exactly what we’re talking about without having to stop what I was doing. ” *G:B*

> “It’s much nicer than having just one screen at a time flipping back and forward, and in many ways when it’s one screen at a time, I feel as if that’s my screen, I don’t want anyone else to get there or do whatever I’m doing, even though it’s a shared space for both screens.” *G:A P1*

Three users preferred fullscreen to overview for browsing however:

> "I just kept the fullscreen view and then I think was good enough to do what I had to do... we were talking to each other all the time, saying 'oh we should look at this movie, or this one" and we're watching the trailer together so yeah, most of the thing was happening when we were talking, rather than when using the system" *G:C*

> "I chose the mode that I preferred, personally, when I was using it I found it best to have what I was doing fullscreen and then whenever I wanted to see what [my partner] was doing I just switched to see his also fullscreen. I didn't really like overview." *G:F P1*
> "For me I liked the fullscreen display more than anything else. I did switch back and forward to see what it was like, but I didn't really like it. If I wanted to see what he was doing I could just mess about and look at it, but 9 times out of 10 I was happy doing my own browsing." *G:F P2*

Three users explicitly mentioned enjoying the slider functionality:

> "I just used the slider depending on what I was doing" *G:B P2*

> "I quite liked having to be able to drag the slider and see more or less of what [my partner] was doing depending on what's going on" *G:D P2*

> "The scrollbar thing is good for watching another person... otherwise if I need to watch the movie or trailer I switched into the bigger view" *G:G*

One group raised an interesting point regarding multi-tasking, suggesting that video content be played in a separate view, so that users were not limited to one interactive view when the content was playing, and that more virtual views could be a useful addition:

> "Maybe if there was an option so you knew you were playing a video then that would be separate and then both people could still do other things whilst the video played" *G:E P1*
> "It would be like opening another tab while you are playing a video and moving the video over to a different screen so you could keep doing things, but then it gets a bit convoluted because there's two people and 3 screens, so technically 4 screens" *G:E P2*

Additionally there was a suggestion regarding better integration of video content, through the system inferring when the fullscreen mode was necessary:

> "I would like [it if]... once there is a video it somehow does it [switches to fullscreen mode] by itself, something like that, maximized kind of thing" *G:A*

4.2.3 DISCUSSION OF EXPERIMENT 3

The results of this study indicated some interesting behaviours regarding how much of the display users were willing to allocate to awareness of others' activity (RQ 2.3). Users of the selective multi-view display dynamically varied awareness of their partners activity, the majority of the time dedicating between 7% and 43% of the display to this, but occasionally dedicating the majority of the display to awareness, whilst either retaining the ability to interact (the peak at 67%), or forfeiting interaction entirely by making the interactive view essentially non-visible (95%). This suggests that this approach could be used to determine empirically how much of a given display should be used for casual awareness (likely varying based on the physical properties of the display). However, given the dynamic usage exhibited it would be worthwhile to expose this functionality to users, if not in a continuous form then perhaps a discrete slider moving through derived ratios.

With respect to how users appropriated the selective multi-view system (RQ 2.4), the management behaviours were utilized in both casual and fullscreen / focused modes, with some users reporting that, in the fullscreen mode, having the ability to transition between views was conveniently like having a "previous channel" button. Notably, three users were entirely unwilling to use the dynamic mode, instead remaining in fullscreen mode for the duration of the Condition. This suggests that in a consumer multi-view system, the ability to transition between views without compromising the maximal rendering of content on the display is an important property for some. However, there is also significant value in incorporating the ability to be casually aware of the activity of other views, for example when performing independent activity but with some shared aspect such as video content.

4.3 CONCLUSIONS AND RESEARCH QUESTION 2

Experiments 2 and 3 resulted in a viable design for a two-user, multi-view TV display. The initial multi-view display evaluated in Experiment 2 was significantly better than the single shared display in terms of the ability to collaborate and operate independently. It demonstrated a set of behaviours which allowed users to effectively share usage of the TV display whilst minimizing the impact on each other's physical view and capability to interact effectively. However, a viewing comparison between this multi-view display and an ideal awareness display configuration using two TVs side-by-side indicated significant differences in terms of how this awareness was accomplished, with much shorter casual glances occurring in the ideal case.

Given this, the design of the multi-view TV display was iterated upon, incorporating mechanisms to allow users to transition between casual and focused states, and dynamically determine their level of engagement with their partners activity when in a casual state. The usage of this "selective" multi-view system confirmed the importance of both modes, demonstrating that given the ability, users will transition between modes and vary their engagement with others' activity. In the fullscreen mode, engagement was varied through transition gestures, whilst in the casual awareness mode users dynamically varied their engagement through use of the view slider for controlling the amount of display given over to casual awareness.

Research Question 2 asked:

> How can TVs support both shared and independent use?

Whilst TVs have the capability to support shared usage, for example through screen division and multi-pointer interfaces, there are notable drawbacks to such implementations. In sharing use of the display in this way, users are forced to attend to any and all activities on the display, increasingly the likelihood of distraction, and typically find their workspace decreases in size proportionally to the number of users (e.g. supporting two users by splitting the TV screen). Moreover, such approaches are not scalable with respect to the number of users, with limitations in display size quickly becoming apparent. In essence, whilst use can be shared, the means by which this use is shared is substandard, compromising others' usage of the display. In addition, there is no capability to facilitate completely independent use across multiple users. Accordingly, to answer RQ 2, this chapter described two experiments investigating the application of multi-view displays to this problem space.

In Experiment 2, it was demonstrated that a multi-view display was a significant advancement over a standard multi-pointer smart TV, allowing for transitions between shared and independent activity, using peeking and transitions between views, whilst removing the distraction of unnecessarily attending to others' activities. However, in comparing the multi-view display with an idealised split-screen approach (using two displays side-by-side to keep the aspect ratio and size of the content viewed comparable across conditions), it was found that casual, glance based awareness occurred frequently, but was not adequately facilitated by the multi-view display behaviours provided.

In Experiment 3, a mechanism allowing for casual awareness on a multi-view display was investigated. Users were provided with the capability to switch between the previous fullscreen peek and transition behaviours, to a dynamic split-screen mode where they could vary their engagement with their partner's activity, and thus control the distraction incurred by incorporating this activity into their view of the TV. It was found that users would vary their reliance on fullscreen and casual awareness modes on the basis of what they wanted to attend to, with trailers often being made fullscreen, whilst collaborative activity occurred in the dynamic split-screen mode. However, there was a subset of users that found the division of the display unacceptable.

The result of these two experiments is the basis of a multi-view smart TV interface, where users can independently choose what they wish to attend to, and can move between tightly coupled collaboration (e.g. sharing the same interface) to loosely coupled collaboration (e.g. casually observing their partner's activity) to completely independent usage (e.g. fullscreen mode on their own personal view). In demonstrating the feasibility and efficacy of such an interface, this chapter answers RQ 2. By using display technologies that overcome the fundamental limitation of one physical view at a time, the extent to which TVs can support both shared and independent use is limited only by the capability of the underlying multi-view display technology.

Given these findings, multi-view TVs should ideally support both transitions between views (and thus independent and shared activity), transitions between focused fullscreen usage and casual awareness of other pertinent activity. Furthermore, there appears significant merit in giving users the ability to dynamically determine their requisite level of awareness based on their engagement with others' activities in this casual awareness state. Fundamentally, this research demonstrates that multi-view TVs have the potential to supplement or supplant the secondary device usage that is now commonplace in the home, bringing interaction and activity back toward a shared-and-shareable focal point, the TV.

Given the results from Experiments 2 and 3, the answer to Research Question 2 is that TVs capable of multi-view rendering (i.e. being able to provide a separate physical view to each viewer) can support shared and independent use through the means by which virtual views are rendered for each viewer. Transitions between virtual views, quickly switching/peeking at a relevant virtual view, and maintaining a casual awareness of others' views during viewing are all important features if a multi-view display is to support shared and independent use, and result in a TV capable of supporting multiple on-going activities without disrupting others' usage.

5. APPROPRIATING THE TV FOR MULTI–SCREEN ACTIVITY

THE TV has been the dominant means of audio-visual media consumption in the home for decades, supporting shared experiences and attracting the gaze and attention of those in the room. However, in recent years, this dominance has been eroded by the advent of "multi-screening", whereby viewers utilize two or more screens or devices at the same time. For example, in Australia 74% of the population that have internet connectivity have dual-screened (meaning they used two screens simultaneously, e.g. using a TV and a phone together), whilst 26% had triple-screened (meaning they typically utilized a combination of TV, phone and tablet / laptop) [103] ($n = 4980$). This transition toward multi-screen usage occurred because the technology and interface of the TV could not keep pace with the demands of users.

Semi-private personal devices offer users the capability to operate entirely independently of those around them, and escape the restriction of having to rely on a single shared medium for consumption. Furthermore, multi-screen devices enabled new multi-tasking behaviours e.g. interacting with or communicating about TV content ("media meshing"), or engaging with content unrelated to the TV content ("media stacking") [165]. However, these devices are often inferior to the TV in some important respects e.g. physical display area, casual accessibility to others, and socialization (with users in their own private "digital bubble" [119], together but alone).

As such, this chapter examines how multi-screen activity can be made more accessible to others. Research Question 3 asks:

> Can TVs provide an awareness of others' collocated multi-screening activity without disrupting existing usage?

This chapter describes Experiments 4 and 5 which answer this Research Question, firstly examining how awareness can be provided through the TV, and secondly examining how disruptive such usage of the TV is to existing viewing, and how awareness can be provided without halting existing viewing. Experiment 4 (Section 5.1) looks at the extent to which multi-screen activity can be made more accessible to others, through utilizing the TV as a shared focal point upon which multi-screen activity can be displayed. Experiment 5 (Section 5.2) builds upon this work by investigating how disruptive shared, mirrored usage of the TV display can be to existing TV viewing, and examines ways to mitigate this disruption given a multi-view capable TV, allowing for non-disruptive awareness of multi-screen activity occurring in the same room.

5.1 EXPERIMENT 4 - COLLABORATIVE SCREEN-MIRRORING

Consumer screen mirroring technology has grown in popularity in recent years, with either Apple's Airplay[1] or Miracast[2] available in most new mobile devices, allowing the mirroring of screen content, as well as driving entirely separate presentations. Additionally, devices capable of displaying this mirrored content are ubiquitous (be it TVs, HDMI dongles such as Chromecast or software servers such as Reflector[3]), whilst projects such as Android Transporter[4] have demonstrated the capability for real-time device-to-device mirroring.

Given that, in the near future, every device in a living space might well support the sharing of device content through mirroring, the issue of who gets to mirror their content, and when, will become more pressing. For example, groups of friends and family sharing a display may be unable to adequately self-organise their usage of this mirroring functionality across their personal devices. More fundamentally, with such capabilities being provided with multi-screen devices by default, there is a technological basis for making the TV the means by which multi-screen activity can be shared and made accessible to anyone in the room, potentially aiding collaboration in the process. This section examines a range of mirroring strategies that groups can use to share and self-mediate use of a receiving display across multiple screen mirroring devices, examining both potential sharing behaviours, and the effect sharing the display has on intra-group collaboration, and activity / artefact awareness in a study.

The study was set within the confines of small group collaboration, to provide a realistic task with which to motivate and stress shared and mirrored usage of the TV (e.g. a small group of friends or family sharing use of a TV in a living room). For the purposes of this study,

[1]http://www.apple.com/airplay/
[2]http://www.wi-fi.org/wi-fi-certified-miracast
[3]http://www.airsquirrels.com/reflector/
[4]http://esrlabs.com/android-transporter/

the TV was to be treated as a commodity, virtualizing ownership of the TV much as control was virtualized in Chapter 3, and influenced by previous work on sharing behaviour [142], as can be seen in Table 5.1.

	Currently Mirroring (Owns Display)	Not Mirroring
Controls	*Relinquish TV* (stop mirroring)	*Take TV* (start mirroring)
	Pass TV (if mirrored use has been requested)	*Request TV* (request mirrored use from current owner)

Table 5.1: An overview of the control functions available to users when both mirroring to the TV, and when not mirroring.

If a user owned the TV, meaning their device was being mirrored to the display, s/he could relinquish it, thereby halting the mirroring process and sending the TV back to an idle screen, or pass it to individuals that requested its use, at which point their device would then be mirrored to the TV. Similarly, if a user did not possess the display, he/she could request or take it from the current owner using buttons overlayed on the screen of the client device. If the display was currently idle, then only the “take display” function was available to users. In this way, users could both manage use of the display manually (by using the “take” function and organising amongst themselves) or use a slower, mediated approach (the “request-pass” function).

5.1.1 EXPERIMENTAL DESIGN

Six groups of three participants took part (male=13, female=5, age mean=22.2, SD=2.81), recruited in groups, on the basis that group members knew each other (being friends / family / colleagues). Additionally, participants were required to be regular users of mobile web browsers.

Whilst there are a number of potential use cases for shared screen-mirroring, it was decided to validate its use through the potential for aiding small group collaboration in the home, evaluated via a collaborative browsing task. A collaborative search task was used, specifically a variant of the travel search task derived from Morris *et al.* [151] in other studies previously [215, 191]. Participants were given 15 minutes to plan a trip to a given city (New York, London, Sydney) and pick tourist attractions and shows to see as a group. These cities were chosen due to their abundance of potential attractions and associated English-language materials online. Participants were free to browse using their devices however they saw fit in relation to the task. This task was ecologically valid, having been shown to be conducted in the home previously, with additional validity derived from the use of consumer mobile devices and the freedom given to participants to use these devices naturally.

Three Conditions were examined:

Condition 1 Mobile devices with no screen-mirroring (as a control; this is analogous to the situation where people use phones to collaborate over an activity);

Condition 2 Mobile devices with one device permanently mirrored (representative of existing consumer screen-mirroring at the time the study was conducted in 2013, where unpairing / pairing devices with Miracast and Airplay was a costly process);

Condition 3 Mobile devices with shared screen-mirroring (use of the TV screen could be passed, taken, relinquished and requested).

The study was carried out within subjects. Conditions were counterbalanced, with task cities assigned such that each Condition had each city twice across the course of the study. For the permanent mirror Condition, the groups were asked to volunteer a member to control the mirrored device.

Participants were seated in a sociopetal arrangement around a table, approximately 2 meters from the shared display, and approximately 30cm from each other (see Figure 5.1). This proximity was chosen both because of its realism (individuals sitting close together on a couch in a living room) and so that participants would have the opportunity to physically share what was on the screens of their devices directly by showing them to each other, to examine whether participants would use the shared display, or instead prefer physically sharing device views.

5.1.2 IMPLEMENTATION

Participants used Android smartphones to control the system and share content, one per participant. These devices were mirrored onto a 46inch HDTV. Mirroring was accomplished via Mobile HD-Link (MHL) cables and an HDMI switch controlled via serial port, with each device attached via an MHL cable to the switch. This was chosen over wireless display technology so as to avoid any issues with bandwidth constraints/contention, transmission issues, or performance. The cables were 3m long and not rigid, thus participants had a good degree of movement/flexibility.

Control of who currently owned the display was managed using controls overlayed on all applications within Android (see Figure 5.1). These controls could be moved via a long-press if they were preventing access to a particular UI element, however they could not be hidden, so as to ensure participants would not forget about the functionality. Button presses

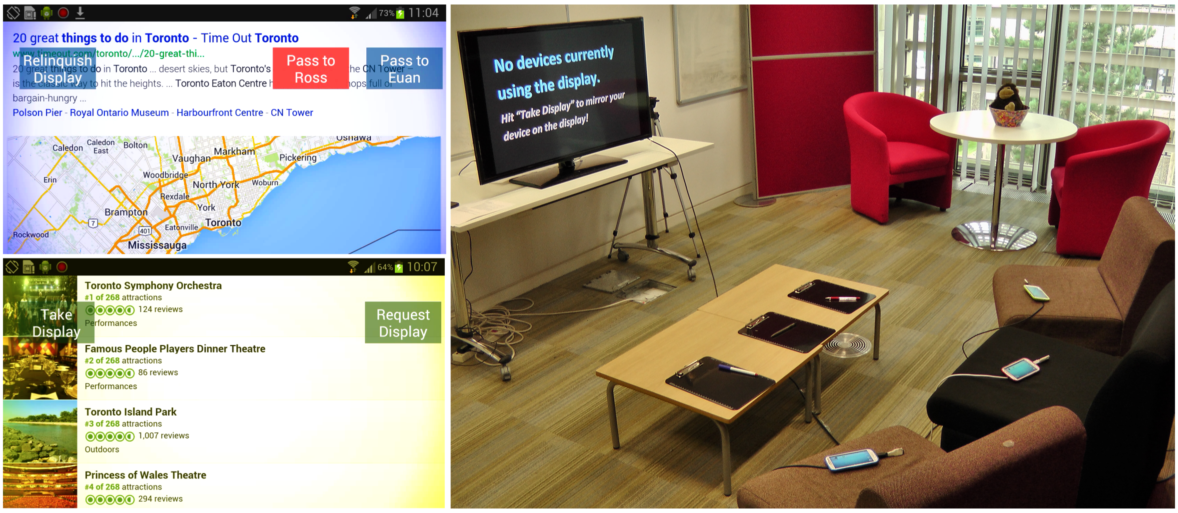


Figure 5.1: Left: client UI (top is current "owner" of the TV, bottom is another participant). The coloured glow around the edges was unique to each device, whilst overlayed semi-transparent buttons enabled management of the shared mirroring TV. Right: Living-room-like space used for conducting study, with 3 phones (one per participant) wired up to the mirroring system.

were relayed to a server controlling the HDMI switch, which in turn changed which device was currently being displayed. The switching delay was approximately 2.2 seconds, during which a black screen was shown. Additionally, when the display was relinquished entirely (i.e. no client owned the display) a screen was shown indicating that clients could mirror to the display by hitting the "take display" button. For a video of the system in use, see [5].

5.1.3 HYPOTHESES AND METRICS

There were two hypotheses in this experiment:

H1 The permanently mirrored display (Condition 2) would lead to greater attention being paid to the activity of the owner of the mirrored device, at the cost of the group's perceived ability to collaborate compared to devices only (Condition 1), due to the dominance of one person's activity in being viewed.

H2 The shared screen-mirroring display (Condition 3) would lead to greater equity of attention across the activities of the group, and thus increased perceived ability to collaborate compared to devices only (Condition 1).

To test these hypothesis, video footage of each participant was recorded and analysed, manually coding timestamps regarding which display the participant was looking at, if any. These timestamps were then parsed to form a viewing array which categorised which display each

[5] https://www.youtube.com/watch?v=kJjcR1eF8us

participant was looking at in 100ms intervals, from which mean viewing and Gini coefficients (as a measure of equity of the viewing distribution [226]; 1 denotes maximum inequality, 0 maximum equality) were calculated. This annotation was conducted once only, by the experimenter alone, due to both ethical and time constraints, given the volume of video to be annotated. Annotations were conducted one clip at-a-time, with breaks between clips, and annotation conducted in ~hour long sessions, with breaks between sessions, in order to guard against errors due to fatigue or lack of concentration.

Viewing logs were generated manually by watching each participant in real time (11 hours footage in total), pressing assigned keys which coded the video log on the basis of which physical display users were attending to. These logs were then combined with logs regarding what content was mirrored, and parsed to extract cumulative viewing and co-viewing data. Footage was captured by a HD video camera placed at seated head height of participants, next to the display such that the annotator could identify whether participants were looking at the display, their devices, or the devices of others in their group. Participants were seated and lit such that these shifts in viewing could be easily discerned by the experimenter *post hoc*.

Post-condition questionnaires were delivered including workload (NASA TLX [87]), and applicable questions derived from previous collaborative browsing studies [215, 191, 152] (7-point Likert-type) asking users about awareness and how effectively they felt they collaborated. See Appendix G for experimental materials (question set and plain language statement given to participants).

5.1.4 RESULTS

Unless otherwise stated, a repeated measures ANOVA was performed with a *post hoc* pairwise Tukey's test for each question/data set. p values less than 0.05 are statistically significant.

5.1.4.1 CUMULATIVE VIEWING

Figure 5.2 shows the cumulative viewing of both the available displays (4 in total, the 3 phones and the TV), and user activity (denoted by seating position), whilst Table 5.2 shows the mean cumulative viewing of a participants activity, broken down by seat and Condition, excluding self-viewing (e.g. the left participant looking at the left phone display) to show the amount that the content on a display was shared with others.

Condition 1 can be seen as being somewhat insular: the outermost participants exhibit limited viewing of the central users activity, and little viewing of each others activity, whilst the central user has a limited awareness of the outer user's activity. With the introduction of

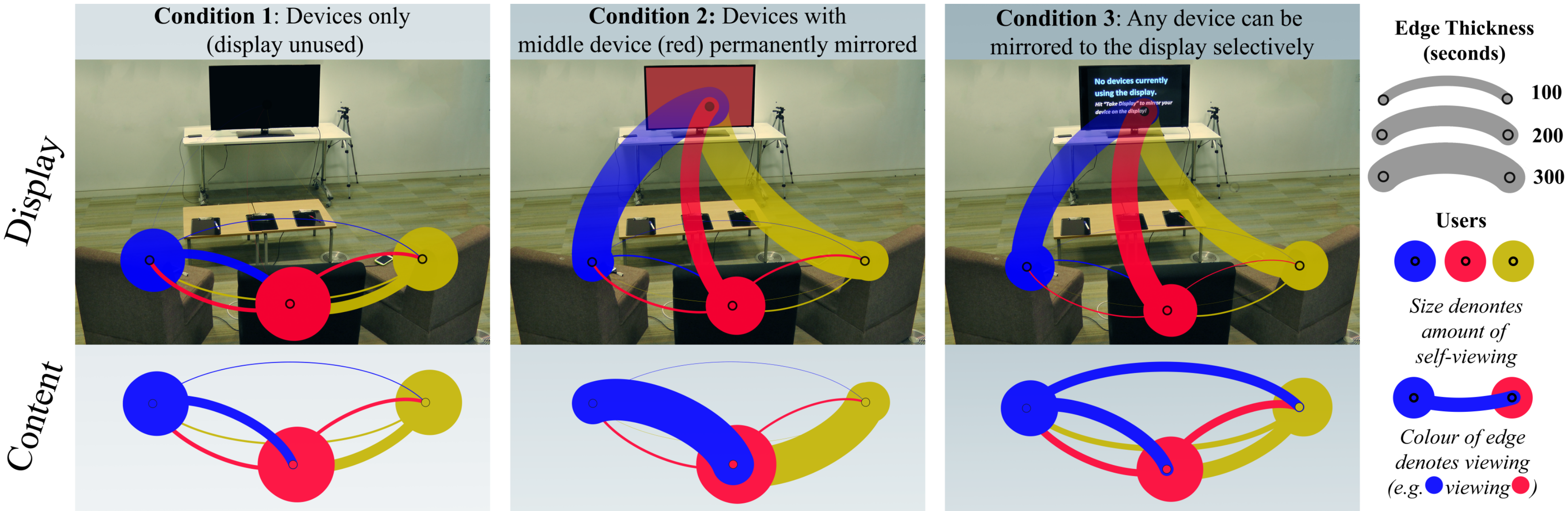


Figure 5.2: Mean cumulative viewing of displays (top) and user content (bottom). Each colour denotes a participant, with edge weight representing the cumulative amount of time spent looking at the node they are directed to. Top shows cumulative viewing time of the displays present (TV, and three mobile devices, one per participant), whilst bottom shows cumulative viewing of user content (presented either on the display, or on the owners device).

the shared display in Conditions 2 and 3, the viewing patterns change significantly, with the shared display offering a focal point for the group. Condition 2 shows a notable disparity in terms of equity of activity viewing; the mirrored user's content dominates the viewing of the group (H1). Condition 3 exhibits greater equity in that respect, with users viewing each others content more than in any previous Condition (H2).

	Mean (SD) Cumulative Viewing (in seconds)		
Participant (by seat)	Condition 1	Condition 2	Condition 3
Left	45.9 (31.9)	25.5 (22.8)	194.2 (135.4)
Middle	221.2 (224.4)	884.0 (534.4)	314.8 (174.7)
Right	65.7 (71.7)	27.6 (43.3)	141.6 (55.0)

Table 5.2: Mean (SD) cumulative content viewed by others (excluding self-viewing) in seconds across groups, by participant position (e.g. in Condition 1, the activity of the participant sitting left was viewed for an average of 45.9 seconds total by the other participants).

This is confirmed in Table 5.3, where the equity of distribution of viewing is significantly different between Condition 2 and Conditions 1 and 3 (however not between Conditions 1 and 3, predominantly because the Gini coefficient does not take into account the magnitude of viewing).

Gini Coefficient of cumulative viewing by group, excluding self-viewing RM-Anova: $\chi^2(2) = 16.3, p < 0.01$				
Condition	Mean Gini Coefficient (SD)	1	2	3
1	0.519 (0.184)	–	$p < 0.01$	$p = 0.07$
2	0.734 (0.138)	–	–	$p < 0.01$
3	0.358 (0.073)	–	–	–

Table 5.3: Mean Gini coefficients across Conditions, calculated from each $3 * 3$ $Left, Center, Right * viewedLeft, Center, Right$ matrix of cumulative viewing, with results of *post hoc* pairwise Tukey's test.

5.1.4.2 CUMULATIVE CO-VIEWING

Two and three person co-viewing denotes any instant of time where two or three users were looking at the same content / activity (with the subset of two person co-viewing within three person co-viewing excluded from two person co-viewing statistics).

Table 5.4 illustrates the equity of distribution of two and three person co-viewing across Conditions: Conditions 1 and 2 feature dominance by the middle participant in terms of activity coviewed, in contrast to Condition 3 where, again, a more equitable distribution of viewing across different participant's activity is demonstrated.

Two Person Co-viewing			
	Mean (SD) Cumulative Viewing (in seconds)		
Participant (by seat)	Condition 1	Condition 2	Condition 3
Left	28.6 (23.8)	18.8 (18.5)	81.3 (74.3)
Middle	109.4 (83.1)	227.8 (68.1)	113.4 (24.3)
Right	22.6 (21.2)	21.4 (35.5)	70.1 (17.6)
Three Person Co-viewing			
Left	5.32 (5.88)	1.17 (1.34)	53.3 (34.59)
Middle	51.87 (74.0)	312.67 (269.94)	92.78 (97.91)
Right	18.75 (27.04)	0.97 (2.37)	32.5 (19.17)

Table 5.4: Mean (SD) cumulative content viewed in seconds across Conditions, by participant position, across both two and three person co-viewing.

Gini Coefficient of Two Person Co-viewing RM-Anova: $\chi^2(2) = 18.36, p < 0.01$				
Condition	Mean Gini Coefficient (SD)	1	2	3
1	0.551 (0.116)	–	$p < 0.01$	$p < 0.05$
2	0.824 (0.208)	–	–	$p < 0.01$
3	0.314 (0.177)	–	–	–
Gini Coefficient of Three Person Co-viewing RM-Anova: $\chi^2(2) = 10.25, p < 0.01$				
1	0.704 (0.263)	–	$p = 0.166$	$p = 0.138$
2	0.907 (0.211)	–	–	$p < 0.01$
3	0.489 (0.151)	–	–	–

Table 5.5: Mean Gini coefficients by two and three person co-viewing, calculated from each $3 * 1$ $viewedLeft, Center, Right$ matrix of cumulative viewing, with results of *post hoc* pairwise Tukey's test.

Table 5.5 confirms this view, with Condition 3 exhibiting the lowest mean Gini coefficients, in contrast to Condition 2 which features the highest mean Gini coefficients, an indicator of the bias toward viewing the middle participants content. Indeed the compulsion to view the shared display is such that it draws the focus of the other participants from their own devices, such that they view the central participant's activity far more than they chose to do so in Condition 1.

5.1.4.3 VIEWING BEHAVIOUR

Viewing was further analyzed by looking at time series histograms of viewing instances (using 0.5 second sized bins) to determine how participants gained awareness. Figure 5.3 shows the viewing of each individual's content broken down by length of view; over all three Conditions, ~75% of the total instances of viewing lasted between 0-6 seconds, however this typically only constituted ~20% of the overall viewing.

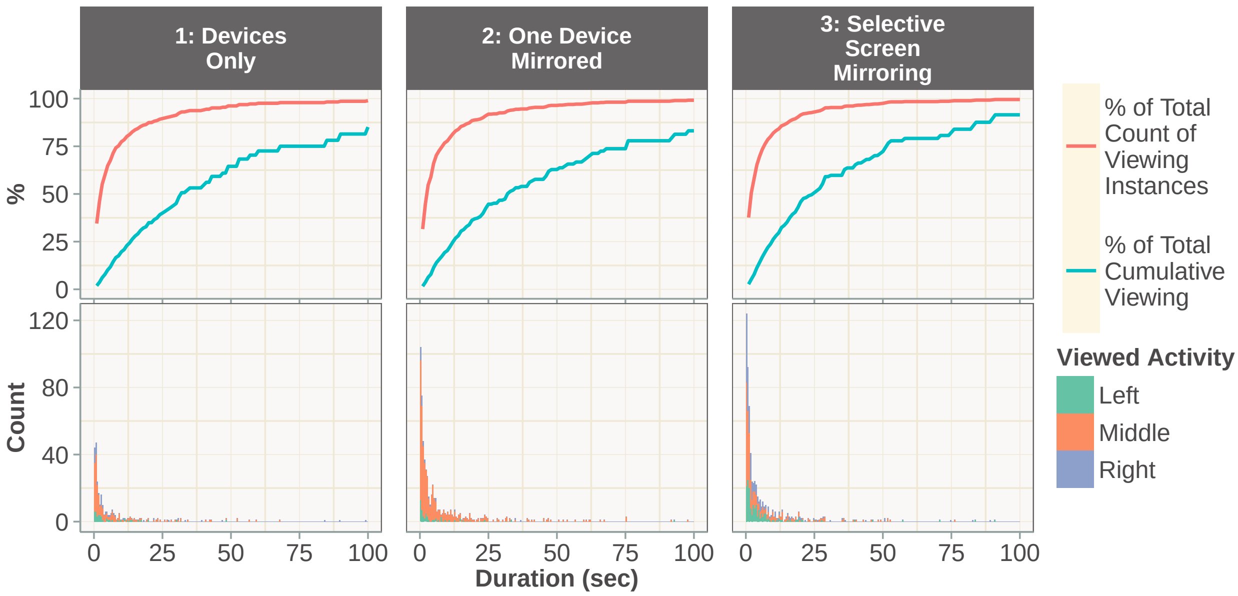


Figure 5.3: Graph of individual viewing behaviour across all participants (excluding self-viewing). Bottom: Histogram presents 0.5 second sized bins counting number of instances of viewing of a given duration. Top: Graph presenting percentage of overall cumulative viewing and percentage of overall number of viewing instances.

Figure 5.4 shows a zoomed in view of Figure 5.3, constrained to viewing instances lasting between 0-10 seconds. Of particular note here is the viewing distribution exhibited: Condition 1 and 2 show similar distributions, with the difference that Condition 2 is ~100% longer at each viewing interval. Condition 3 shows a similar viewing distribution to Condition 2 (with a heavy right skew toward the 0-2 second bins), however a greater proportion of the left and right participants activity is now apparent.

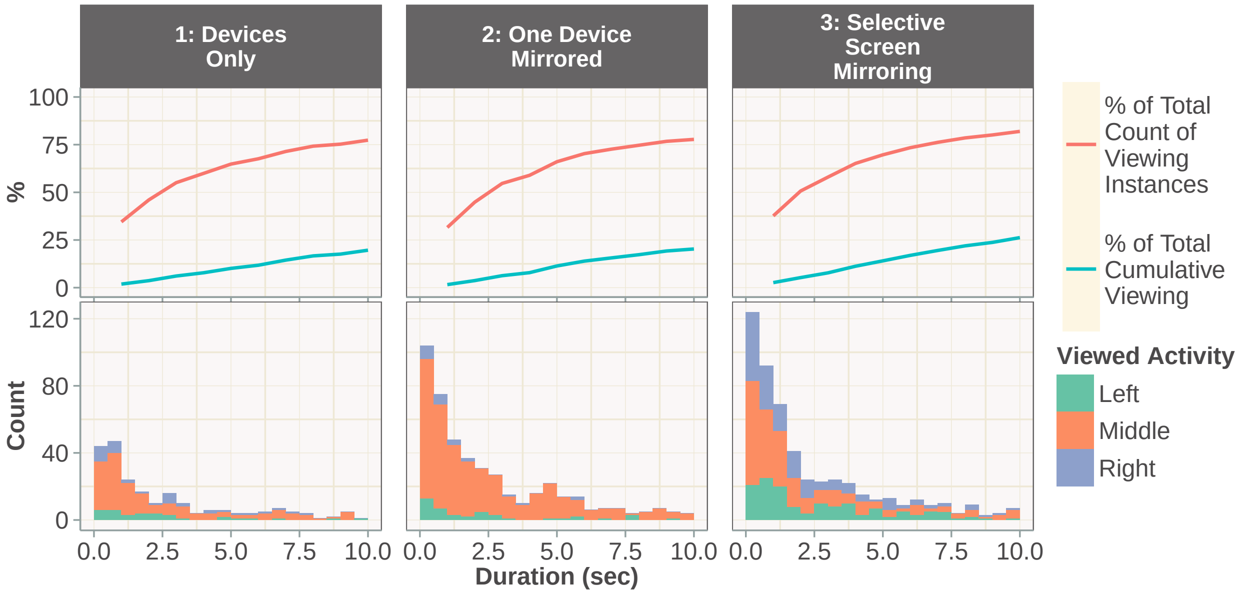


Figure 5.4: Graph of individual viewing behaviour across all participants (excluding self-viewing), focussing on viewing instances between 0-10 seconds. Bottom: Histogram presents 1 second sized bins counting number of instances of viewing of a given duration. Top: Graph presenting percentage of overall cumulative viewing and percentage of overall number of viewing instances.

5.1.4.4 Co-viewing Behaviour

The distributions of two and three person co-viewing behaviour (see Figures 5.5 and 5.6) exhibit many of the same traits as previously discussed, for example the heavy right-skewed distribution, and the majority of the viewing instances lasting between 0-6 seconds in length.

Of note within these Figures is the extent to which co-viewing occurred using the devices (infrequently), or using a combination of device and shared display (frequently), as an indicator of how often pairs or tuples of participants shared the common focal point of a device. Whilst two and three person co-viewing still utilized devices as shared screens in Conditions 2 and 3, the occurrence of this behaviour decreased significantly, with the majority of co-viewing involving a combination of device and shared display. This transition toward heavy use of the shared display illustrates its potential usefulness above and beyond device based sharing.

Indeed, three person co-viewing was barely prevalent in Condition 1, however this behaviour was clearly facilitated well by the shared display, hence the orders-of-magnitude increase in three person co-viewing when the shared display was introduced in Conditions 2 and 3.

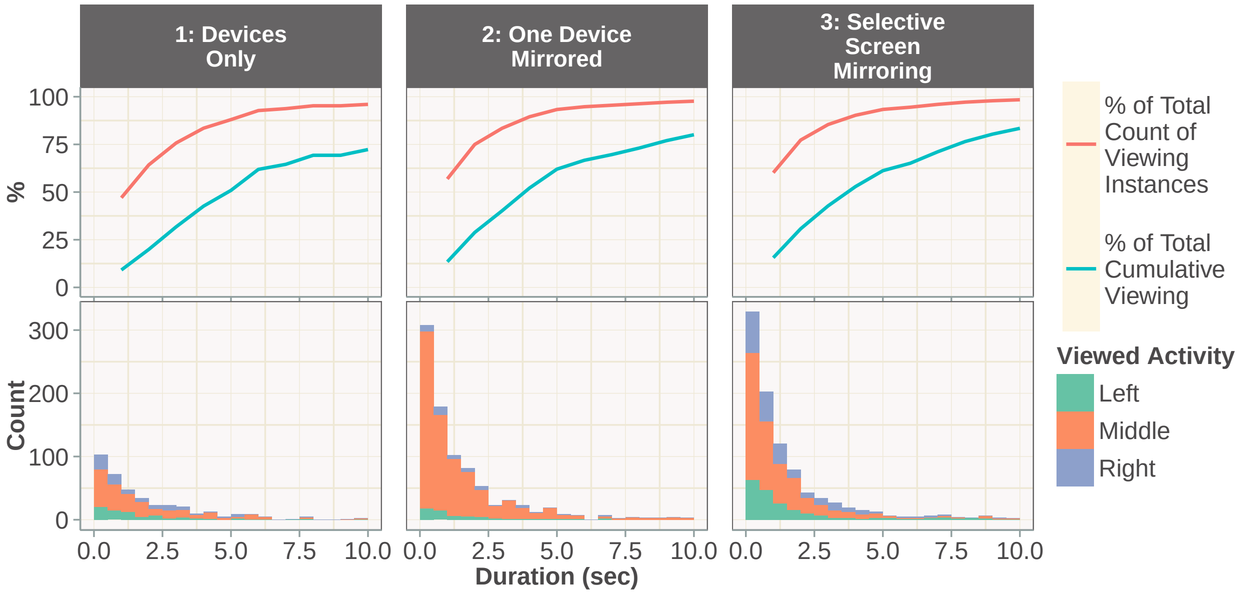


Figure 5.5: Graph of two person co-viewing behaviour across all participants. Middle: Histogram presents 0.5 second sized bins counting number of instances of viewing of a given duration, involving mixed-mode viewing (i.e. a combination of TV/device). Top: Graph presenting percentage of overall cumulative viewing and percentage of overall number of viewing instances. Bottom: Histogram of viewing excluding TV.

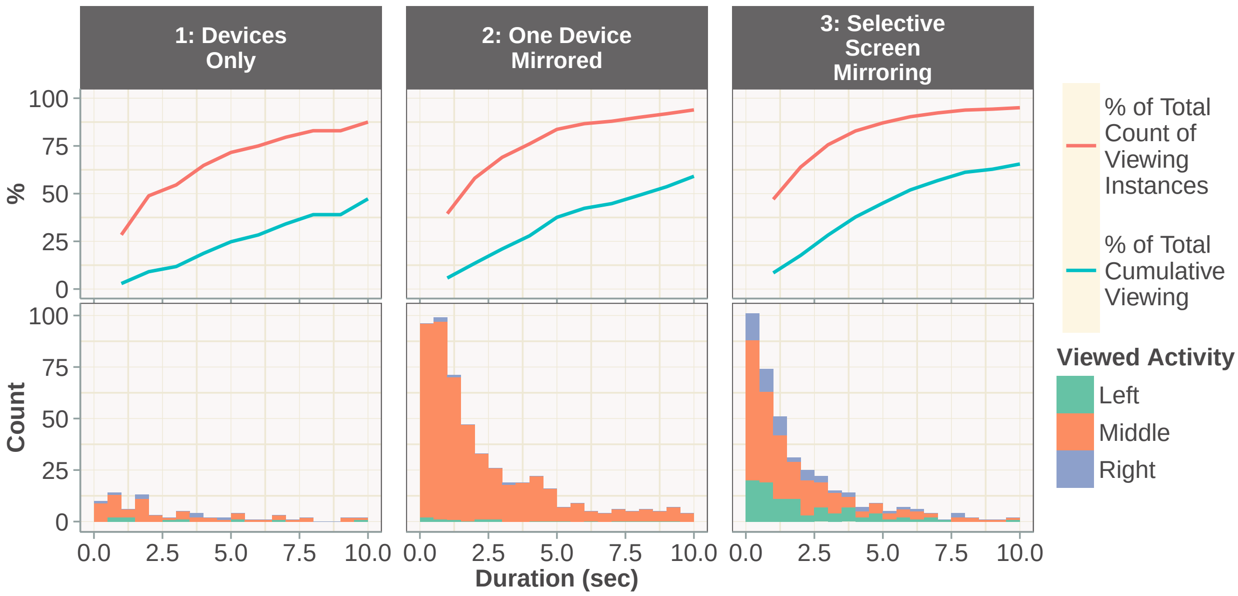


Figure 5.6: Graph of three person co-viewing behaviour across all participants. Middle: Histogram presents 0.5 second sized bins counting number of instances of viewing of a given duration, involving mixed-mode viewing (i.e. a combination of TV/device). Top: Graph presenting percentage of overall cumulative viewing and percentage of overall number of viewing instances. Bottom: Histogram of viewing excluding TV.

5.1.4.5 QUESTIONNAIRE

The post-condition questionnaires (see Table 5.6) revealed some of the consequences of both providing a mirrored display, and facilitating shared-mirroring. In terms of perceived collaboration, users responded positively to the shared screen mirroring, with statistically better ratings in response to WS-1 and MO-1 with respect to Condition 3. Indeed WE-1 indicated why this was so, with users reporting a significant different in terms of awareness of what others were doing, indicating awareness was improved by the shared screen mirroring system.

Of note was the response to **"We were able to work independently to complete the task"** with Condition 2 found to be significantly different (for the worse) than both Condition 1 and 3, suggesting that the fixed screen dominance actually compromised independence within the group. There was also a presentational aspect to the system, with the responses to MO-4 suggesting users took control of the display to present information to the group and aid in discussion.

There was no significant different in terms of overall workload, however subjective performance (NASA-TLX performance question) improved ($\chi^2(2)$=6.71, p<0.01), with *Post hoc* Tukey's indicating means were significantly different between Condition 3 (*MD=13.9, SD=3.56*) and Condition 2 (*MD=11.7, SD=4.69*)).

Table 5.7 details custom questions for this study regarding comfort using the system, privacy, and questions specific to Condition 3. Of these, the most pertinent insight was into privacy, with the shared display Conditions exhibiting significantly more user concern regarding privacy. Whilst Condition 2 is somewhat confounded by the fact that only one person was mirrored to the display (and thus likely only one person had significant privacy concerns), the result for Condition 3 suggests that privacy is a significant issue, even with the ability to stop mirroring when necessary.

Question	Condition 1	Condition 2	Condition 3	Friedman Test	Wilcoxon *Post-hoc* ($p < 0.05$)
WS-1: We were able to collaborate effectively	3.94 (1.55)	4.28 (1.23)	5.17 (0.924)	$\chi^2(2) = 8.03, p < 0.05$	3-1, 3-2
WS-2: We were able to work independently to complete the task	4.89 (1.08)	3.33 (1.37)	4.78 (1.22)	$\chi^2(2) = 12.7, p < 0.01$	3-2, 2-1
WS-3: It was easy to discuss the information we found	4.06 (1.63)	4.72 (1.18)	5.39 (0.85)	$\chi^2(2) = 11.6, p < 0.01$	3-1
WS-4: We were able to work together to complete the task	4.67 (1.08)	4.72 (1.23)	5.33 (1.08)	$p = 0.053$	NA
WS-5: I was able to actively participate in completing the task	4.72 (1.27)	4.67 (1.37)	5.44 (0.984)	$\chi^2(2) = 6, p < 0.05$	None
MO-1: How well did the system support collaboration?	2.83 (1.82)	3.67 (1.71)	5 (1.08)	$\chi^2(2) = 11.5, p < 0.01$	3-1, 3-2
MO-2: How well did the system support you to share particular information with a particular user in the group?	3.11 (2.05)	3.28 (1.87)	4.83 (1.29)	$\chi^2(2) = 8.03, p < 0.05$	3-1, 3-2
MO-3: How well did the system support you to share particular information with everyone in the group?	2.17 (2.18)	3.94 (1.98)	5.17 (1.04)	$\chi^2(2) = 16, p < 0.01$	2-1, 3-1
MO-4: How well did the system support you to see/review what the other users were talking about?	2.89 (1.97)	3.39 (1.69)	5.22 (1.06)	$\chi^2(2) = 12, p < 0.01$	3-1, 3-2
WE-1: The system was helpful in completing the given task	3.28 (1.64)	4.17 (1.25)	5.06 (1.06)	$\chi^2(2) = 14, p < 0.01$	3-1
WE-2: I was aware of what other users were doing	2.83 (1.54)	3.39 (1.61)	4.78 (1.31)	$\chi^2(2) = 14.7, p < 0.01$	3-1
TLX: Overall Workload (ANOVA)	31.30 (14.44)	32.04 (17.87)	28.47 (18.15)	$\chi^2(2) = 2.05, p = 0.36$	NA

Table 5.6: Questions derived from previous studies. WS: WebSurface[215], MO: Mobisurf[191], WE: WeSearch[152]. Questions were 7-point Likert scale (results range from 0-6, higher is better). Means with standard deviations are presented across Conditions. A Friedman test was conducted with *post hoc* Bonferroni corrected Wilcoxon tests unless otherwise labeled (ANOVA) in which case a repeated measures ANOVA with *post hoc* Tukey's test was performed.

Question	Condition 1	Condition 2	Condition 3	Friedman Test	Wilcoxon *Post-hoc* ($p < 0.05$)
ME-1: I would be comfortable using this system with friends	4.44 (1.69)	4.61 (1.38)	5.44 (0.86)	$\chi^2(2) = 6.9, p < 0.05$	None
ME-2: I would be comfortable using this system with family	4.39 (1.69)	4.61 (1.54)	5.17 (1.15)	$\chi^2(2) = 6.0, p = 0.05$	NA
ME-3: I would use this system in my home	3.89 (1.68)	4.61 (1.04)	4.78 (1.11)	$\chi^2(2) = 5.2, p = 0.07$	NA
ME-4: I would have privacy concerns if using this system with others (higher is worse)	0.56 (0.86)	2.50 (1.86)	2.06 (1.69)	$\chi^2(2) = 15.0, p < 0.01$	3-1, 2-1
ME-5: How acceptable did you find requesting use of the display/passing the display?	-	-	4.72 (1.36)	NA	NA
ME-6: How acceptable did you find taking the display from whomever currently possessed it?	-	-	4.83 (1.34)	NA	NA
ME-7: How intrusive did you find the permanent buttons on the screen for managing the display? (higher is worse)	-	-	3.5 (1.65)	NA	NA
ME-8: I found the colour based glow around the screen adequately helped me determine if I currently owned the display	-	-	3.72 (1.97)	NA	NA
ME-9: I found the colour based glow around the screen adequately helped me determine who owned the display	-	-	3.56 (1.92)	NA	NA
ME-10: I felt adequately notified when someone requested the display from me	-	-	4.50 (1.38)	NA	NA

Table 5.7: Custom questions created for this study. Questions were 7-point Likert scale (results range from 0-6, higher is better unless otherwise stated). Means with standard deviations are presented across Conditions. A Friedman test was conducted with *post hoc* Bonferroni corrected Wilcoxon tests unless otherwise labeled (ANOVA) in which case a repeated measures ANOVA with *post hoc* Tukey's test was performed.

5.1.4.6 CONTROLS FOR MANAGING MIRRORED DISPLAY

With respect to participant usage of the control scheme for the shared screen mirroring system, Table 5.8 shows that taking the display from whomever currently possessed it was the prevalent means of display management, in contrast to the request-pass mechanism implemented, which required not one action (pressing the take button), but two actions across two users (pressing the request button and waiting for the receiver) to transfer the display.

	Request	Pass	Take	Relinquish
Total Occurrences	18	17	59	13
Mean Acceptability (SD)	4.72 (1.36)		4.83 (1.34)	NA

Table 5.8: Usage of display management controls provided in Condition 3. Acceptability ranged from 0 (lowest) to 6 (highest) on a 7-point Likert scale. N.B. One participant was omitted as an outlier for having a request count more than two standard deviations from the mean.

Whilst participants reported feeling adequately notified when someone requested the display (mean: 4.5, SD: 1.38), one participant's results were omitted due to a large amount of requests made in a short period, potentially indicating issues with such mechanisms if the requester feels that the owner of the display has not been adequately notified, or has chosen to ignore the request.

5.1.5 DISCUSSION

The results show that by introducing a mirrored display that does not support flexibly changing the content or activity mirrored to it, there are a number of effects on collaboration, specifically in terms of compromising the independence of collaborators and compromising a group's ability to be aware of each members activity. The proposed shared screen mirroring solution allowed for the independence that users found when using only mobile devices for collaboration, whilst significantly improving group awareness of individual's activity.

5.1.5.1 EQUITY OF AWARENESS AND INDEPENDENCE

The results for cumulative group viewing suggest that the primary factor inhibiting the viewing of others content is the accessibility of that view; in the device-only Condition, viewing, and co-viewing, were dominated by the central participant, whose device was most easily accessible to the other group members. This poses a problem, in that there are a subset of group users that are essentially cut off from observing each other. The central user, whose view is most accessible, contributes disproportionately to the collaborative experience.

Given that the experimental seating arrangement was designed to be accessible and sociopetal, it could be expected that these issues would be exacerbated in a real-world living room environment, where the seating arrangements are less accessible, and potentially dispersed over a greater area. Thus the large TV display provides obvious benefits regarding being able to make whomever is in the room aware of your activity, in a way that does not disrupt their current ongoing device activity in the room.

Indeed this is where it would be expected that current screen-mirroring technology (at the time of conducting the experiment) would provide an ideal means toward facilitating better awareness of activity. However, the results show that this is not the case; in utilizing a screen-mirroring solution that does not facilitate multi-user management of the shared display (Condition 2) only one user (whomever has paired to the screen-mirroring device) has the ability to share with the group. This compromises collaboration by undermining the independence of the other users: the shared display, and by extension the user's activity that is mirrored to that display, is viewed to the extent that said user essentially leads the collaborative task. This result supports H1. There may be cases where this is beneficial, however in this study this was not the case. The reasons for this are that in this Condition, there still exist the dual problems of there being a subset of group users that are essentially cut off from observing each other, and one user contributing disproportionately to the collaborative experience.

The results suggest that these problems can be addressed by exposing a simple set of functionality for enabling flexible use of the mirroring display. The shared screen mirroring system (Condition 3) has been shown to improve perceived collaboration, as well as providing an equity of awareness which allows every user to potentially contribute and present to the group as a whole, and allows users to retain their independence. This result supports H2.

5.1.5.2 SELF-MANAGEMENT OF THE DISPLAY: TAKING IS SHARING

The system enabled a basic set of functionality for transferring and relinquishing use of the display: request-pass, take, and relinquish; of these, participants showed a strong inclination toward taking the display, both in terms of frequency of use, and self-rated acceptability. In opening the display up to be managed by members of the group, this allowed users to work fluidly together, using their social capabilities to determine the acceptability of taking the display (to present their own activity or content to the group) at any given moment.

5.1.5.3 SHARED FOCUS OF ATTENTION

Utilizing the shared display additionally provided a shared focal point for the group; incidence of two and three person co-viewing increased dramatically in the shared display

Conditions, providing users with a shared reference point which likely aided in the communication and discussion necessary for effective collaboration, as suggested by the user's perceived ability to collaborate. Indeed, this represents an additional benefit regarding utilizing the display over, for example, tablet or mobile devices for providing awareness, as the shared display typically provides a reference point accessible to anyone in the room.

5.1.6 CONCLUSIONS FROM EXPERIMENT 4

Screen mirroring technology where a single device / user is paired with a TV can aid collaboration in groups. However, there are negative side effects, specifically with respect to group awareness being dominated by the activity of the mirrored user, leading to the compromise of independence within the group. Shared screen mirroring system significantly improves a small group's ability to collaborate, by enabling device users to pass, request, take and relinquish the display as required. Through a basic set of behaviours for managing use of the display, the shared screen mirroring system was shown to better facilitate collaboration and content sharing in small groups, resulting in greater equity of participation and awareness of others' activity. In opening the display up to the group, this allowed fringe members to more actively participate, sharing content with members they were unlikely to share with previously. As such, shared screen mirroring represents a viable extension to existing screen mirroring technologies that could be readily implemented, within the Miracast standard for example, enabling new sharing behaviours and interactions and lending further value to screen mirroring in the home.

However, in considering RQ 3, there are some notable limitations with this approach. Firstly, such a system can provide awareness of only one user at-a-time, with no ability for concurrent display of multiple multi-screening devices. In addition, fullscreen mirroring necessitates that any existing activity on the TV be interrupted and replaced when a multi-screening device is mirrored. Thus, whilst this system partially satisfies the first clause of RQ 3 ("To what extent can TVs provide an awareness of others' collocated multi-screening activity"), it does not satisfy the second ("without disrupting existing usage").

5.2 EXPERIMENT 5 - MULTI-VIEW SCREEN-MIRRORING

Given the limitations of Experiment 4, regarding both concurrent display of multi-screen activity, and providing awareness alongside existing TV activity, the aim of Experiment 5 was to investigate these two aspects of usage. Specifically, it was to examine how multiple devices could be mirrored concurrently alongside existing TV content, and what effect this had in terms of compromising use of the shared display, for example through increased visual load, decreased area for representing mirrored content and the loss of a single shared focal point. This section examines the extent to which users can attend to multiple devices on one TV display, the effect this and prior systems has had on existing TV viewing, and proposes ways in which users can be aided in managing their viewing of device activity on the TV.

In addition, the concept of the “Connected Home” is considered within the context of screen mirroring. The “Connected Home” [86] refers to the idea that the devices in the home will eventually be interconnected through local networks, in a local “Internet of Things”. With respect to screen mirroring, the connected home is becoming a reality, with a variety of devices providing the capability to view their activity on-demand from any display. For example Sony Remote Play and PS Vita TV, Wii U Off-TV Play, and nVidia Shield game streaming all allow the ability to remotely view and in some cases control activity on other devices via phones, tablets, or TVs. This potential “always-on” approach to screen-mirroring could be applied to the awareness of activity on devices such as phones or tablets, allowing users to “dip in” to content and activity occurring around the household, but raises questions regarding privacy, acceptability, and scope of use. As such, this section also examines the potential for new approaches toward the accessibility of screen-mirrored activity, investigating systems which allow users to attend, personally and privately, to whichever device activity they wish using multi-view displays, and examining the social and privacy implications of having passively shared, “always-on” screen-mirrored devices.

5.2.1 AIMS

Given the prior results of Experiment 4, the aim was to examine specific Research Questions regarding how screen mirroring might be used in the home, namely:

RQ 3.1 - Fragmentation of viewing To what extent does taking use of the display fragment and disrupt existing usage e.g. viewing TV content, and can this fragmentation be reduced through screen division approaches?

RQ 3.2 - Screen division Do the potential benefits of screen division approaches (e.g. viewing multiple content streams simultaneously) outweigh the potential negative effects (e.g. distraction, increased complexity of the system used to manage the display), as evidenced by user preferences?

RQ 3.3 - Inferred focus Can the complexity of a screen division-based mirroring system (e.g. visual complexity, workload managing the display) be reduced through inferring focus on activities, and would this be acceptable?

RQ 3.4 - Active versus passive screen-mirroring Previous systems have relied on actively and explicitly mirroring the personal device, however given the potential for devices that are always available to be viewed, what effect would turning control of viewing over to the viewer have on the mirroring experience, in terms of acceptability, awareness, and privacy considerations?

To investigate these questions, a prototype screen-mirroring system was created, capable of displaying up to three content views simultaneously, in the form of a TV content view, and the mirrored displays of two Nexus 4 Android 4.X phones. To evaluate these Research Questions four Conditions were required:

1 - Shared screen mirroring This was the baseline, analogous to the most used elements of the screen mirroring system from Experiment 4, providing users with the capability to take the display (at which point their device was mirrored fullscreen) or stop mirroring (at which point the TV would revert to playing previously viewed TV content).

2 - Split-screen mirroring Here each user was able to selectively choose to show / hide both their own device and the TV content, with the screen layout changing as appropriate to accommodate the content being viewed. If both TV and device content was visible on the display, users would have the option to select which they wished to listen to.

3 - Inferred split-screen mirroring This Condition builds upon Condition 2 (split-screen mirroring) by inferring focus on content dynamically. If a device was visible on the TV and audio was detected, that device would be made fullscreen and listened to, inferring focus based on device activity. When the device stopped producing audio, the system would revert back to its previous state. The intention here was that if the participant was viewing a movie trailer, that the system would pause the TV and focus on the trailer for the duration the trailer was viewed.

4 - Multi-view passive screen mirroring To allow users to independently determine which mirrored device content they attended to, this Condition would utilize a multi-view display giving users completely independent views upon which they could selectively mirror whichever content they wished. Management of audio was shared between users as with split-screen mirroring.

In all Conditions the TV content would pause if not visible, and resume playback when visible. All user functions were made accessible via an on-screen UI that was rendered on-top of phone activity, as seen in Figure 5.7. The visibility of these buttons could be toggled, and the buttons could be moved via long press if necessary.

The Android devices were locked to landscape and wirelessly mirrored (both video / audio, H264 encoded to 520p resolution, using a modified version of BBQScreen[6]) to a PC where

[6]https://screen.bbqdroid.org/

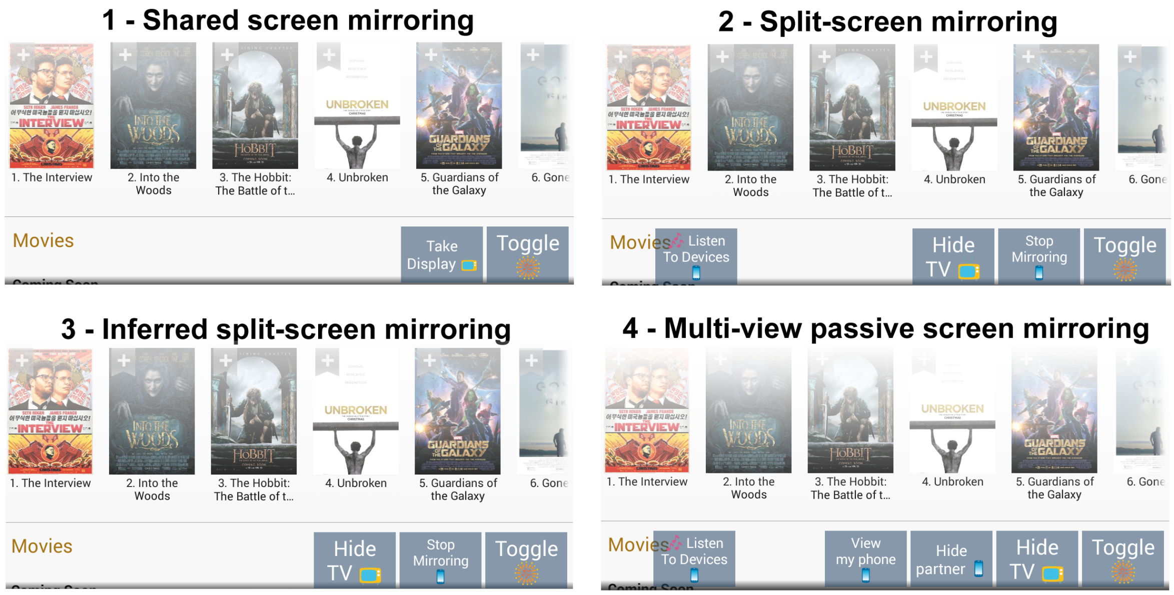


Figure 5.7: Mirroring UI: buttons controlling the mirroring functions were rendered on-top of all phone functionality, with the ability to toggle their visibility and move the buttons via long-press.

they, along with TV content, were captured and dynamically rendered on a 24 inch 120 Hz display. The rendering software could dynamically display any combination of the mirrored devices and TV content, allowing for anywhere from one to three content views (TV and two devices) to be shown on a users given view (see Figure 5.8). For a video of the system in use, see [7].

For Conditions 1-3 the TV operated as a single-view display. In Condition 4 it was used as a multi-view display presenting users with entirely separate physical views. To do this, the approach of Experiment 2 (see Section 4.1.1) was again used, with a nVidia 3D vision 120 Hz display and active shutter glasses being used to create a two-view multi-view display. For Condition 3 (inferred mode) a sliding 1 second window calculated the average audio volume devices being mirrored; if this exceeded a set threshold the device was considered to be playing audio-visual content. When a device was visible on the display, an eye icon was rendered in the top-left corner of the device to inform the participant their activity was being viewed on the TV.

5.2.2 Experimental Design

For the task a combination of TV viewing and collaborative media browsing was used. Users were instructed to browse a given set of categories of movies in the Android IMDB app whilst watching companion TV content together, with the task of selecting movies to watch together

[7] https://www.youtube.com/watch?v=4jqVVRmmCmA

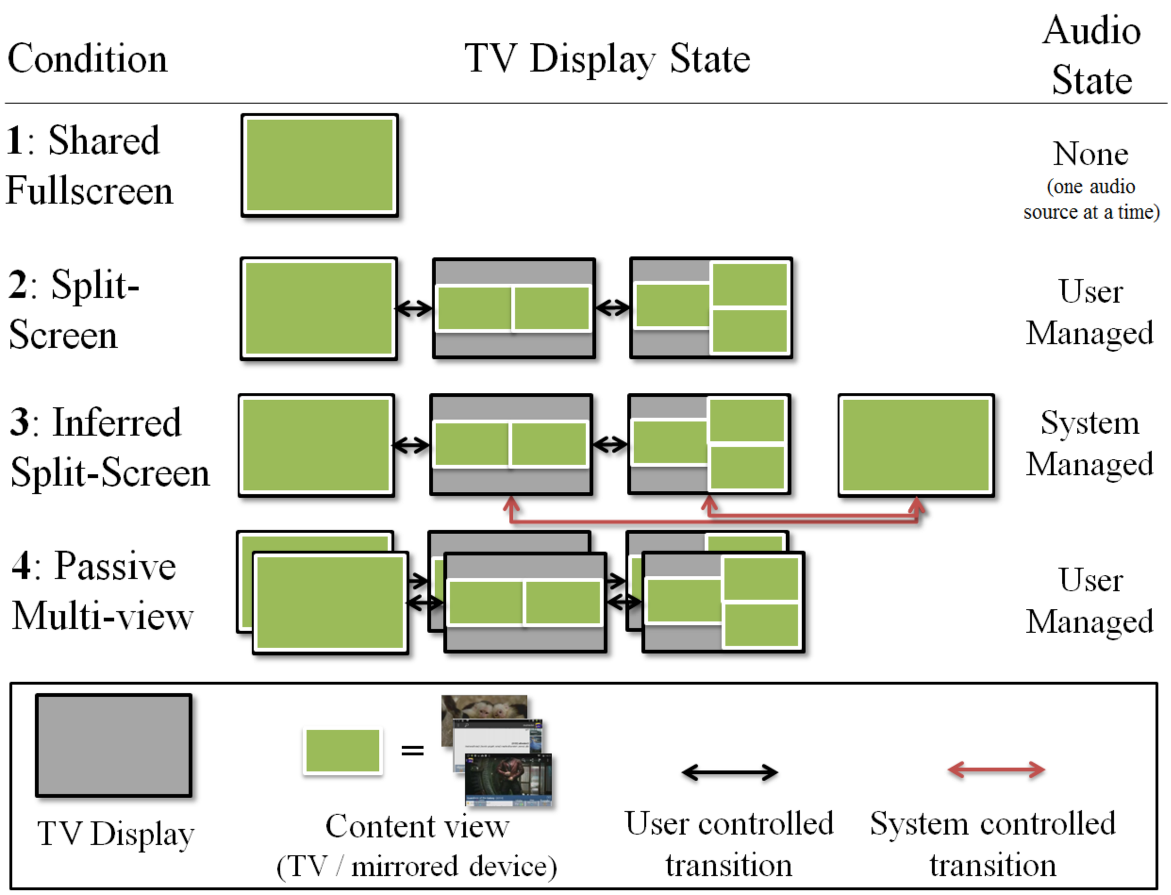


Figure 5.8: Overview of display and audio management across Conditions. In Conditions 2, 3, and 4 the system could dynamically layout up to 3 content views out of the available device views and TV content view, based on what the user(s) wished to monitor. In Conditions 1, 2, and 3 (utilizing a standard single-view TV) there was one shared user view. In Condition 4 (using a multi-view TV) there were two independent views.

later, for the duration of each Condition. Whilst browsing for movies they would also be watching a nature documentary in place of TV content, providing a motivation to use the TV as standard. Four movie categories were selected for each Condition, with users instructed they could browse them however they saw fit. Additionally, users had the capability to watch trailers (with the instruction to moderate trailer viewing time to 30 seconds per trailer). Users were tested for 10 minutes per Condition in a within-subjects design. Users were evaluated in a mock living-room setting, with efforts put in to making this space living-room-like (e.g. comfortable sociopetal seating). Whilst other approaches were considered, such as a real-world deployment, the prototype nature of the system prevented this e.g. only supporting two physical views (and thus two users).

There were 12 pairs (24 users, mean age=21.9, SD=4.3, 21 male, 3 female) recruited from University mailing lists as pairs that knew each other (intimacy groups e.g. friends, family) so that they would be able to collaborate realistically. Given that the system involved the mirroring of smartphone activity and thus required a level of familiarity with smartphone interaction, regular smartphone users were recruited. Conditions were counter-balanced. In terms of dependent variables, users' ability to collaborate effectively, and garner awareness of their partners activity was measured through a questionnaire derived, from the questionnaires used in Experiments 2–4, which also included workload (NASA TLX) [87], which was measured for both the task being conducted, and the workload in viewing the companion TV content, and usability (System Usability Scale (SUS) [24]). Viewing was logged only in terms of what was displayed on the TV (and was thus available to view by the users). Viewing based on gaze was not recorded, due to the use of the active-shutter glasses prohibiting any manual coding of gaze by denying the experimenter a clear view of the participants eyes. UI actions (e.g. choosing to view or mirror a device) were also logged. See Appendix H for experimental materials (question set and plain language statement given to participants).

5.2.3 RESULTS

5.2.3.1 DISPLAY VIEWING

Shared screen mirroring (Condition 1) featured the lowest total TV and device viewing, with the screen-division Conditions allowing for simultaneous viewing of both TV and device activity (see Figure 5.9). Notably, the multi-view Condition featured less device viewing than the other screen-division approaches, as well as the most TV viewing, indicative of benefits of this Condition in terms of allowing users to attend only to the content they wished.

The shared screen mirroring Condition also featured the most fragmented TV and device viewing (see Figure 5.10), with the lowest duration viewing instances of all Conditions. The

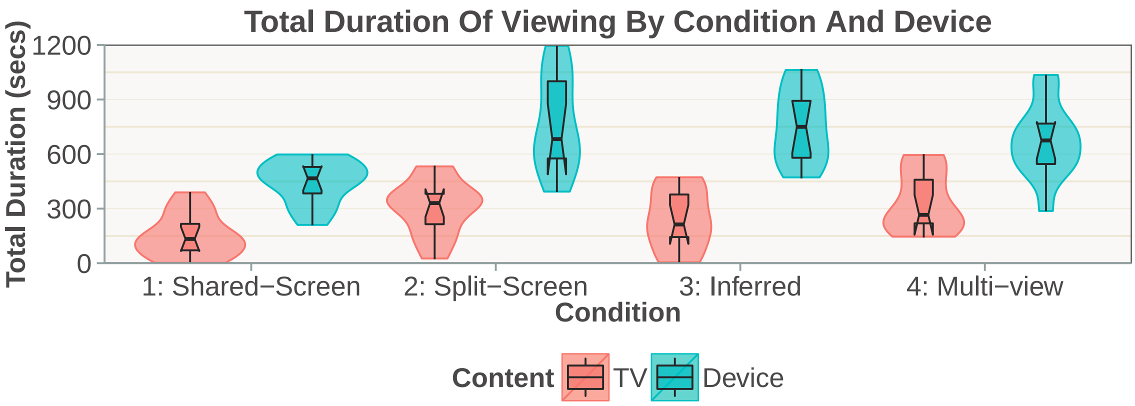


Figure 5.9: Total duration of viewing of TV and Device content by Condition. For Condition 4 viewing was divided by 2 to adjust for independent user views of the display. RM ANOVA for TV viewing: $\chi^2(3) = 22.88, p < 0.01$, *post hoc* Tukey's Test: 1-2, 1-4, and 3-4. RM ANOVA for Device viewing: $\chi^2(3) = 21.87, p < 0.01$, *post hoc* Tukey's Test: 1-2, 1-3. and 1-4.

screen-division Conditions were used to view only one content view at a time for approximately half of the total viewing (see Figure 5.11), with users less reliant on two and three views, however screen-division was still used for approximately half the viewing time across Conditions.

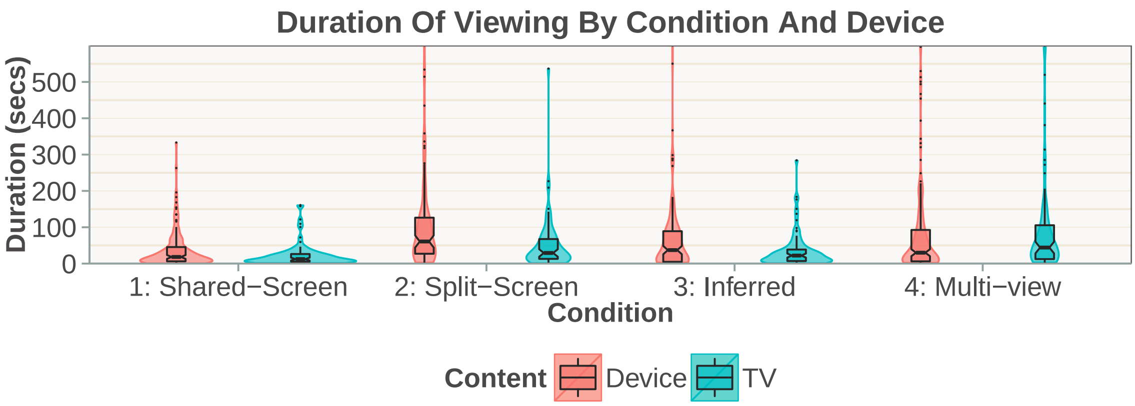


Figure 5.10: Duration of viewing instances by content (TV and Device) and Condition. RM ANOVA for TV viewing: $\chi^2(3) = 14.56, p < 0.01$, *post hoc* Tukey's Test: 1-4, 3-4. RM ANOVA for Device viewing: $\chi^2(3) = 11.69, p < 0.01$, *post hoc* Tukey's Test: 1-2.

In Condition 4 (Multi-view) there was a tendency toward having two views displayed as opposed to three, indicative that in multi-view users would often choose to attend to the TV and their partners device, with device viewing biased toward their partners device (mean=384 seconds, SD=167 seconds) rather than their own device (mean=290 seconds, SD=187 seconds). In Condition 3 the inferred mode functionality resulted in focused mirroring of audio-visual device content on average for 248.83 seconds (SD=129.13 seconds), indicating inferred mode was active a significant proportion of the time.

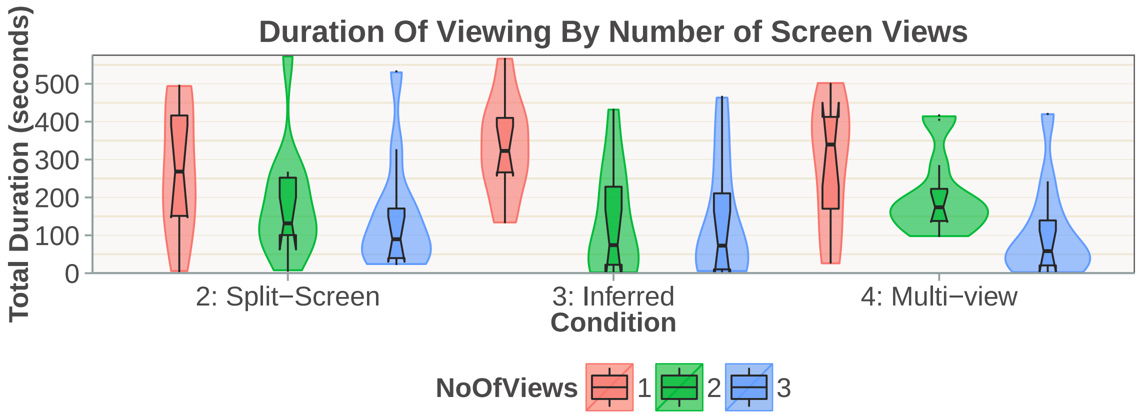


Figure 5.11: Total Duration of viewing content by number of content views on display (1 to 3 views selected from TV and the two participant's devices). Condition 1 was omitted from statistics tests as it supported showing only 1 view at a time. RM ANOVA for 1 view: $\chi^2(2) = 1.79, p = 0.41$. RM ANOVA for 2 views: $\chi^2(2) = 2.01, p = 0.37$. RM ANOVA for 3 views: $\chi^2(2) = 1.34, p = 0.51$.

5.2.3.2 USAGE OF SYSTEM

For an overview of the actions taken by users, see Table 5.9.

Viewing Action	Condition			
	1: Shared-Screen (1 button)	2: Split-Screen (3 buttons)	3: Inferred (2 buttons)	4: Multi-view (4 buttons)
Own Device	9.32 (5.93)	6.41 (3.22)	5.95 (6.45)	5.91 (3.71)
Partners Device	NA	NA	NA	9.77 (7.99)
TV	NA	5.86 (4.09)	3.50 (3.46)	6.05 (5.95)
Toggle Audio	NA	3.50 (2.82)	NA	3.45 (2.32)
Total Viewing	9.32 (5.93)	12.27 (5.77)	9.45 (7.82)	21.73 (13.47)
Total All Actions	9.32 (5.93)	15.77 (7.29)	9.45 (7.82)	25.18 (13.72)

Table 5.9: Mean (Std. Dev.) total mirroring UI actions by function. NA indicates function was not applicable for the given Condition. Viewing actions refer to any action which toggled the mirroring of the specified content view to the display. RM ANOVA for Total Viewing Actions: $\chi^2(3) = 37.20, p < 0.01$, *post hoc* Tukey's Test: 1-4, 2-4, 3-4. RM ANOVA for Total All Actions: $\chi^2(3) = 49.78, p < 0.01$, *post hoc* Tukey's Test: 1-2, 1-4, 2-3, 2-4, 3-4.

Action counts for the majority of Conditions reflected the number of functions available i.e. the more functions or buttons there were available to use, the more action counts. The exception to this was the inferred system (Condition 3), which featured similar mean total actions to the shared-screen system (Condition 1) and significantly lower total actions compared to Condition 2, confirming that automatic management lowered workload with respect to managing the display. Condition 4 featured the most user actions of the Conditions.

5.2.3.3 WORKLOAD AND USABILITY

User workload measured both how effectively they performed the overall task of viewing TV whilst browsing movies (TLX Task) and how effectively they managed to watch the TV content (TLX TV). Condition 4 featured the highest workload (see Figure 5.12 and Table 5.10) across Conditions, reflecting the previous usage demonstrated in the action counts. This was most evident in the effort subscale, with significantly increased effort. The inferred mode of Condition 3 did decrease workload compared to Condition 2, however not significantly so. Condition 1 featured the lowest workload of all the Conditions. In terms of usability, the SUS scores indicate that the increased complexity of Conditions 2 and 4 impacted perceived usability, with Condition 1 featuring the highest rating.

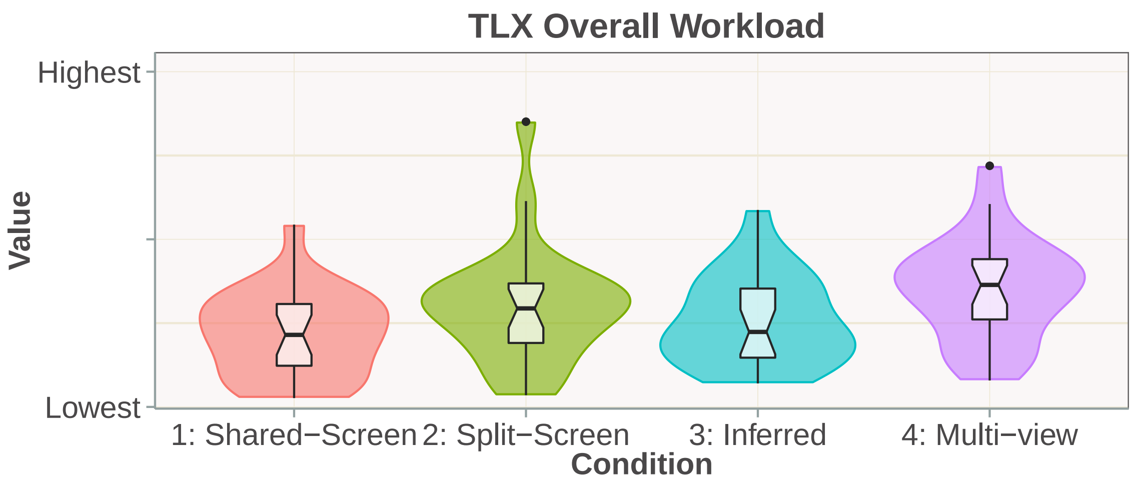


Figure 5.12: Overall workload for task - Friedman test $\chi^2(3) = 16.28, p < 0.01$, *post hoc:* 1-4, 3-4

Table 5.11 details questions from prior collaborative studies. WS-4 suggests that the passive screen-mirroring multi-view display impacted participants ability to work together compared to the single-view displays, suggesting that active screen-mirroring may be beneficial in some respects, but also reduced distraction (DIST-1) and allowed for finer control of their awareness of their partners activity (DIST-2).

In examining DIST-1 in more detail (see Figure 5.13) it is evident that the shared screen-division approaches led to increased distraction due to unnecessary or unwanted attention being paid to the partners activity, distraction minimized in the multi-view passive screen mirroring Condition and the shared-screen mirroring Condition, where there could only be one view at a time competing for attention.

Figure 5.14 suggests that whilst Conditions 1 and 4 shared similar levels of distraction, they differed regarding how well users could control their awareness; the downside to Condition 1 was the lack of control over gaining awareness of their partners activity.

Question	Condition 1	Condition 2	Condition 3	Condition 4	Friedman Test	Wilcoxon *Post-hoc* ($p < 0.05$)
TLX: TV Effort	5.92 (5.68)	6.92 (4.89)	5.13 (3.93)	8.38 (4.53)	$\chi^2(3) = 10.55, p < 0.05$	3-4
TLX Task: Effort	5.50 (3.89)	6.92 (4.67)	5.38 (4.14)	9.50 (4.05)	$\chi^2(3) = 24.66, p < 0.01$	1-4, 2-4, 3-4
TLX: TV Frustration	4.13 (5.41)	4.79 (5.47)	3.00 (3.90)	4.33 (4.83)	$\chi^2(3) = 8.18, p < 0.05$	None
TLX Task: Frustration	3.08 (4.41)	3.92 (4.18)	2.71 (2.99)	3.96 (4.27)	$\chi^2(3) = 5.46, p = 0.14$	NA
TLX: TV Mental Demand	4.88 (5.50)	7.79 (4.67)	5.63 (4.01)	9.08 (5.11)	$\chi^2(3) = 15.57, p < 0.01$	1-2, 1-4, 3-4
TLX Task: Mental Demand	4.17 (3.45)	7.63 (4.89)	6.46 (3.91)	8.75 (4.76)	$\chi^2(3) = 17.68, p < 0.01$	1-2, 1-3, 1-4
TLX: TV Physical Demand	3.54 (4.12)	4.83 (4.76)	4.29 (4.66)	5.83 (4.31)	$\chi^2(3) = 8.85, p < 0.05$	None
TLX Task: Physical Demand	3.21 (2.55)	4.67 (4.56)	3.96 (3.70)	5.67 (3.71)	$\chi^2(3) = 9.07, p < 0.05$	1-4
TLX: TV Performance	11.92 (5.45)	11.08 (4.77)	12.46 (4.33)	12.50 (3.97)	$\chi^2(3) = 3.45, p = 0.32$	NA
TLX Task: Performance	14.75 (3.29)	13.42 (3.06)	13.83 (3.54)	14.46 (2.36)	$\chi^2(3) = 3.22, p = 0.36$	NA
TLX: TV Temporal Demand	5.21 (5.47)	5.42 (4.69)	5.71 (4.78)	6.96 (4.62)	$\chi^2(3) = 3.01, p = 0.39$	NA
TLX Task: Temporal Demand	4.63 (4.02)	5.75 (4.56)	5.71 (4.12)	7.75 (4.53)	$\chi^2(3) = 8.97, p < 0.05$	1-4
TLX: TV Overall Workload	25.62 (19.28)	31.39 (17.33)	25.24 (14.71)	34.24 (15.65)	$\chi^2(3) = 15.55, p < 0.01$	3-4
TLX: Task Overall Workload	20.69 (12.13)	28.72 (16.60)	24.48 (12.67)	33.47 (14.55)	$\chi^2(3) = 16.28, p < 0.01$	1-4, 3-4
SUS: System Usability Scale	83.75 (13.95)	73.02 (15.32)	82.60 (15.47)	73.85 (17.91)	$\chi^2(3) = 8.50, p < 0.05$	None

Table 5.10: Workload and usability. NASA TLX [87] is from 0 (lowest) to 100 (highest), SUS [24] is from 0 (worst) to 100 (best). Means with standard deviations are presented across Conditions. A Friedman test was conducted with *post hoc* Bonferroni corrected Wilcoxon tests.

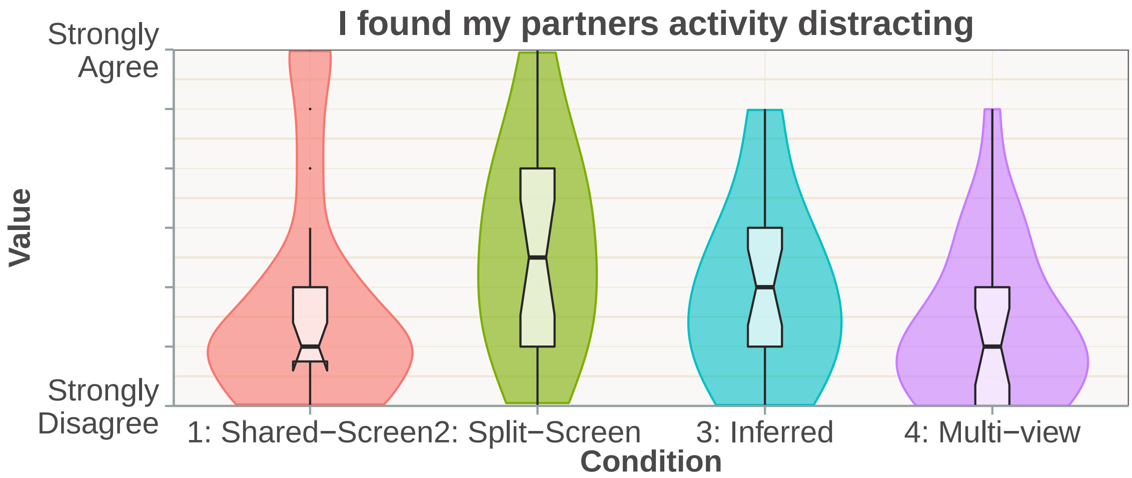


Figure 5.13: Responses to “I found my partners activity distracting” (lower is better) - Friedman test $\chi^2(3) = 12.63, p < 0.01$, *post hoc* Bonferroni corrected Wilcoxon test showed no significant differences.

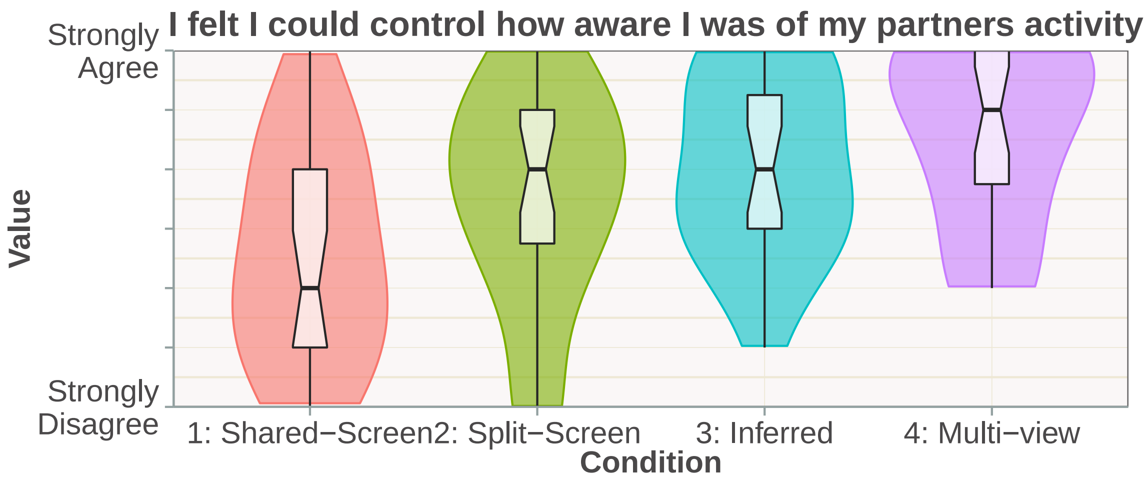


Figure 5.14: Responses to “I felt I could control how aware I was of my partners activity” (higher is better) - Friedman test $\chi^2(3) = 15.52, p < 0.01$, *post hoc* Bonferroni corrected Wilcoxon test showed differences between 3-4.

Question	Condition 1	Condition 2	Condition 3	Condition 4	Friedman Test	Wilcoxon *Post-hoc* ($p < 0.05$)
WS-1: We were able to collaborate effectively	4.92 (1.41)	4.67 (1.20)	5.04 (0.86)	4.46 (1.41)	$\chi^2(3) = 6.31, p = 0.09$	NA
WS-2: We were able to work independently to complete the task	4.88 (1.39)	4.67 (1.24)	4.92 (1.21)	5.29 (1.16)	$\chi^2(3) = 7.35, p = 0.06$	NA
WS-3: It was easy to discuss the information we found	5.17 (1.34)	5.17 (0.96)	5.38 (0.65)	4.92 (1.18)	$\chi^2(3) = 4.66, p = 0.19$	NA
WS-4: We were able to work together to complete the task	4.88 (1.33)	5.04 (0.91)	5.29 (0.75)	4.50 (1.53)	$\chi^2(3) = 10.7, p < 0.05$	3-4
WS-5: I was able to actively participate in completing the task	5.00 (1.06)	5.09 (0.83)	5.38 (0.65)	5.08 (0.93)	$\chi^2(3) = 3.77, p = 0.29$	NA
MO-1: How well did the system support collaboration?	4.88 (1.19)	4.71 (1.37)	5.08 (0.97)	4.79 (1.67)	$\chi^2(3) = 0.37, p = 0.95$	NA
MO-2: How well did the system support you to share particular information with your partner?	5.00 (1.22)	5.25 (0.79)	5.42 (0.78)	5.13 (1.15)	$\chi^2(3) = 1.27, p = 0.73$	NA
MO-3: I was able to tell when my partner was looking at what I was browsing	4.04 (2.27)	4.46 (1.67)	4.54 (1.31)	3.83 (2.26)	$\chi^2(3) = 0.61, p = 0.89$	NA
MO-4: How well did the system support you to see/review what your partner was talking about?	4.71 (1.63)	5.08 (0.83)	5.08 (1.06)	5.08 (1.14)	$\chi^2(3) = 0.16, p = 0.98$	NA
WE-2: I was aware of what my partner was doing	3.88 (2.09)	4.67 (1.20)	4.79 (1.29)	4.79 (1.53)	$\chi^2(3) = 4.25, p = 0.24$	NA
PE-1: My partner was aware of what I was doing	3.71 (1.99)	4.79 (1.18)	4.54 (1.35)	4.67 (1.34)	$\chi^2(3) = 4.35, p = 0.23$	NA
DIST-1: I found my partners activity distracting	1.71 (1.83)	2.67 (1.71)	1.88 (1.45)	1.29 (1.30)	$\chi^2(3) = 12.63, p < 0.01$	None
DIST-2: I felt I could control how aware I was of my partners activity	2.54 (1.77)	3.54 (1.82)	4.08 (1.50)	4.58 (1.53)	$\chi^2(3) = 15.52, p < 0.01$	1-3, 1-4
ME-1: How well did the system support viewing the TV content	4.67 (1.55)	4.67 (1.58)	5.04 (0.86)	5.20 (0.88)	$\chi^2(3) = 2.45, p = 0.48$	NA
ME-2: How well did the system support viewing device activity?	4.75 (1.42)	4.88 (1.08)	4.96 (0.95)	5.12 (1.03)	$\chi^2(3) = 2.89, p = 0.41$	NA
ME-3: How satisfied were you with your capability to listen to the TV and the devices being mirrored?	4.17 (1.89)	4.00 (1.61)	4.25 (1.70)	4.21 (1.29)	$\chi^2(3) = 1.42, p = 0.70$	NA
ME-4: I found the TV to be distracting	1.75 (1.85)	1.96 (2.05)	1.29 (1.23)	2.21 (1.89)	$\chi^2(3) = 4.99, p = 0.17$	NA

Table 5.11: Questions derived from previous studies. WS: WebSurface[215], MO: Mobisurf[191], WE: WeSearch[152], PE: Permulin[125]. Questions were 7-point Likert scale (results range from 0-6, higher is better). Means with standard deviations are presented across Conditions. A Friedman test was conducted with *post hoc* Bonferroni corrected Wilcoxon tests.

For user rankings (see Figure 5.15) all Conditions were somewhat dichotomous, with no significant differences, albeit the multi-view passive screen mirroring Condition featured the best mean ranking, followed by the inferred Condition.

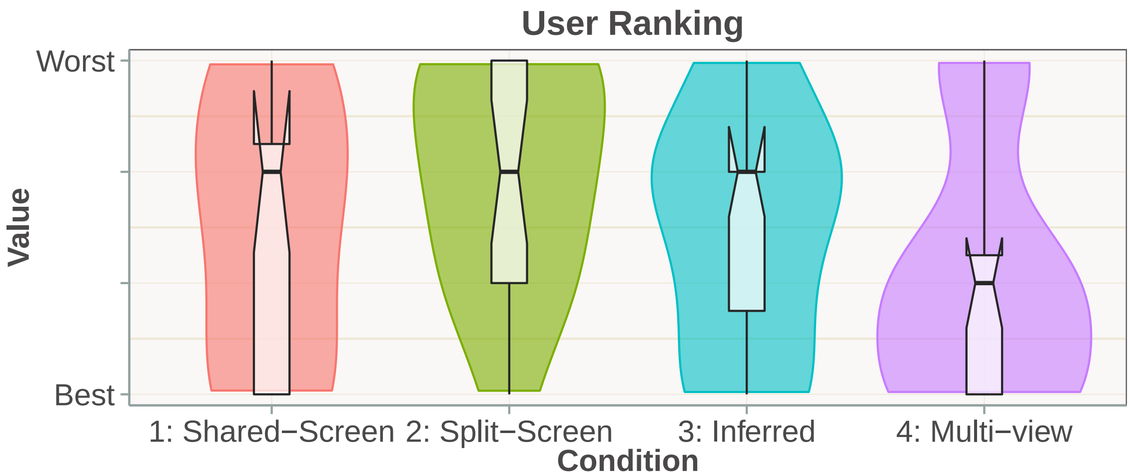


Figure 5.15: User ranking (lower is better) - Friedman test $\chi^2(3) = 5.55, p = 0.14$.

5.2.3.4 ACCEPTABILITY AND PRIVACY

As part of the debrief groups were asked whether there were any aspects of the systems they used that they liked or disliked, probing for detail where appropriate. Table 5.12 lists the most frequently mentioned common themes during these interviews. For quotes, G# indicates Group number.

Being able to choose to view their partners content or the TV independently was a frequently cited benefit of Condition 4 (passive multi-view):

> "I liked the last one, it was the best one. I could do whatever I want, I was independent." *G2*

Comment	No. Of Participants
Liked Condition 4 (multi-view)	11
Liked inferred focus function	7
Disliked Condition 1 (fullscreen)	5
Liked simplicity of Condition 1 (fullscreen)	4
Disliked Condition 4 (multi-view)	3
Found 3 views complex	2

Table 5.12: Most mentioned aspects of system usage.

> "I liked the one with the glasses the most too because I wasn't distracted by those videos he was watching and I was independent to choose my screen." *G3*
> "The last one was very unusual and convenient." *G6*

Participants also appreciated the ability of Condition 3 to automatically infer usage of the display:

> "I liked the fact that when you start a trailer it comes up on the big screen, that's handy." *G4*
> "I liked the (Condition 3) where it senses the video is played and it pauses the TV, because then I don't have to explicitly say play the sound for this." *G5*

However, user preferences were divisive, as the previous rankings illustrated. For example some preferred the simplicity and speed of Condition 1:

> "I preferred the third one where it was fullscreen on the one press of a button, because it was the fastest to share with the other person and the sound also was changed automatically." *G6*
> "I kind of liked the simplicity of just the normal pushing things to the screen and taking them back." *G10*

Whilst others believed it might lead to conflict:

> "On the last one I feel like it was me and my sister doing it we would get in a lot of fights." *G7*
> "The second one was just not helpful because you could just steal the screen, I was fighting trying to watch TV and he takes the TV." *G8*

Users raised privacy concerns regarding personal device usage, specifically regarding privacy filtering of screen content, when to make the screen available to be viewed, and awareness regarding whether someone is viewing the screen:

> "The only thing is that you can control what they see on their screen, I think you'd have to be able to control what you can see and what you can't see.. you could be like, texting your girlfriend you know?" *G8*

> “I liked having the option to show my device but I wouldn’t mind having it be automatic in some cases... If I’m viewing a video or a trailer... I want it to be available automatically. It would be a bit cumbersome if I was to explicitly say this app can be shared” *G5*
> “I quite liked being able to dip in and out of viewing, so if you were talking about a film I could see what you were viewing then close it again” *Partner interrupts*: "I didn’t know that was happening, and I feel kind of weird about that..." *G10*

The issue of spatial/social context affecting shareability was also raised:

> “If I’m in the living-room with other people and IMDB or Youtube are white-listed then fine, share it with others. If I’m in bed watching stuff then I don’t want people in the other room to see what I’m doing because that’s happening without my knowledge.” *G5*
> “I would have privacy concerns if I’m not using this at home among people that I don’t know for a long time... with friends and family wouldn’t be a problem” *G2*

5.2.3.5 ACCEPTABILITY OF SHARING

As the final part of the debrief participants were also asked to rate the social acceptability of different screen mirroring behaviours, namely:

User control of mirroring “The user of the device chooses when, and for how long, to mirror the device to a TV”

Selective sharing for on-demand viewing “The user of the device chooses to make the device available and accessible to others in the home to view on-demand on the TV for a period of time”

Always-on sharing “Others in the home can view the device on-demand at any time”

For this set of mirroring behaviours, acceptability of usage of these behaviours was elicited against two additional factors: privacy, and device ownership. For device ownership personal devices (e.g. their phone) and shared devices (e.g. family tablet) were considered, whilst for privacy, no privacy filtering was contrasted against having the capability to automatically filter device content where privacy was likely to be violated (with the examples given of hiding notifications or only sharing certain application activity). The aim of this was to establish firstly which sharing behaviours were most acceptable. Secondly, the extent to which immediate privacy concerns regarding shared activity might impact adoption. And thirdly, whether usage of personal devices might influence willingness to share their device activity. The results of the acceptability questionnaire can be seen in Figure 5.16.

A factorial three-way repeated-measures ANOVA showed a significant effect on the type of screen sharing only, with no significant effects on privacy filtering or device ownership. This suggests that the biggest concern regarding the acceptability of sharing device activity through screen mirroring is regarding the possibility of "always-on" sharing, with users preferring that the device be made available to be viewed selectively, regardless of device

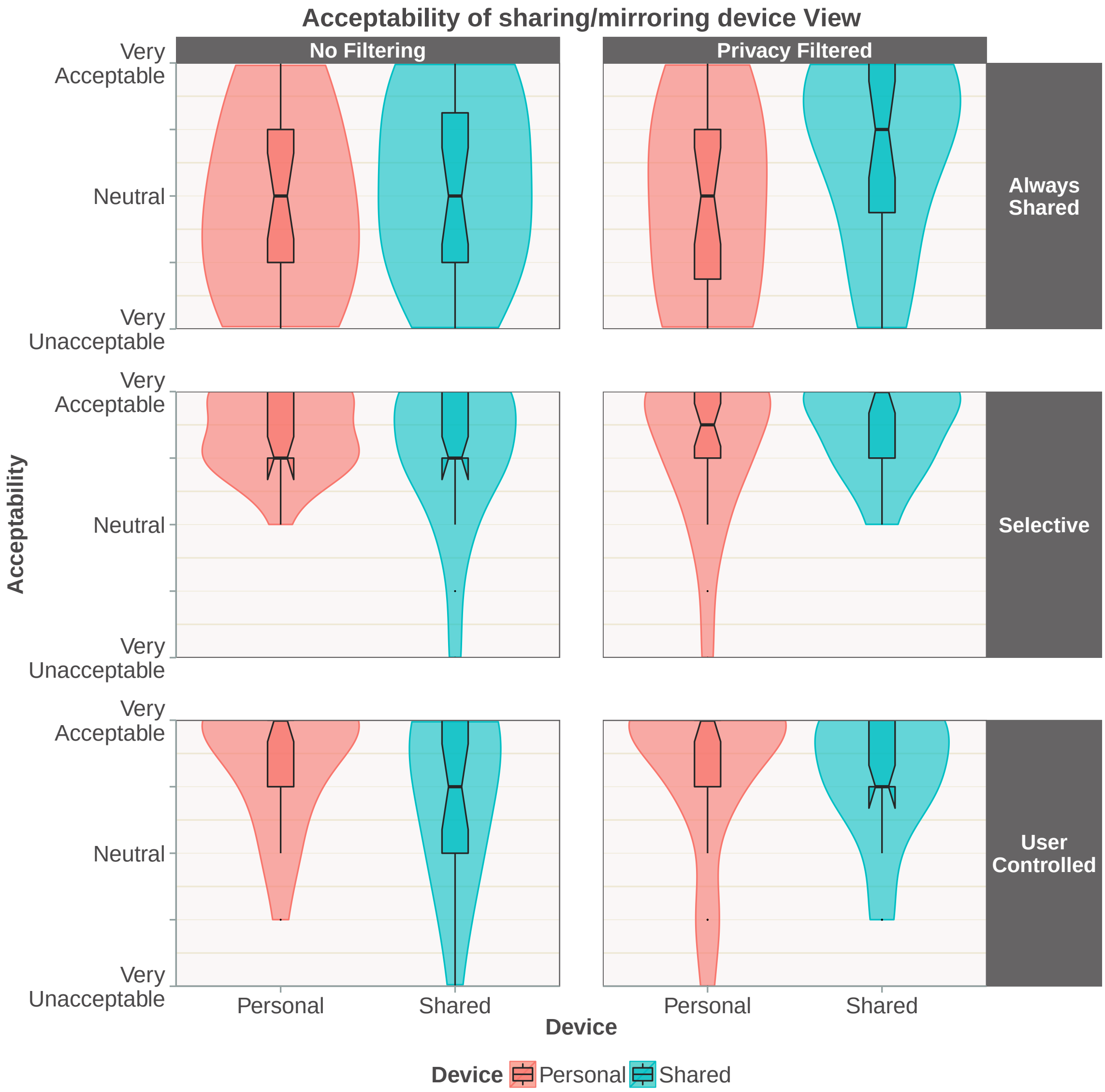


Figure 5.16: A factorial RM ANOVA found a significant effect on the type of sharing questioned $F(2, 92) = 22, p < 0.01$, *post hoc* Tukey's on sharing found significant differences between Selective - Always Shared, and User Controlled - Always Shared. There were no interaction effects.

ownership or the suggested real-time privacy filtering measures.

5.2.4 DISCUSSION OF EXPERIMENT 5

The results of this study provided a number of insights into the usage of screen-mirroring behaviours on a shared-use TV. With respect to RQ 3.1 (fragmentation of viewing), in attempting to utilize screen-mirroring whilst consuming TV content there is significant fragmentation regarding the TV viewing experience, as evidenced by viewing instance durations. Whilst this is rather obvious, it does at least underline the necessity of having the ability to pause TV in screen-mirroring contexts, to preserve some semblance of a TV viewing experience. Fragmentation is naturally reduced using screen-division.

Screen-division in fact allows for greater awareness of the activity of others whilst preserving TV viewing, as evidenced by the questionnaire responses (addressing RQ 3.2 - screen division), but at the expense of an increase in distraction; with multiple content streams on the TV at once, and each user having no control over whether other user's content was mirrored, this forced attention is unavoidable. Additionally, the workload (measured by TLX) of managing multiple content streams on the display is significant. The inferred focus Condition (RQ 3.3 - inferred focus) addressed this issue, evidenced by decreased TLX effort subscale scores, improved SUS (usability) scores, decreasing distraction (questionnaire), and improving user ranking. This suggests that, for screen-division approaches to be feasible, the TV needs to be able to help users adaptively manage what is on the display / what they listen to.

Finally, with respect to active versus passive screen mirroring (RQ 3.4), distraction, control over awareness, independence, and user rankings were rated best for this Condition. The multi-view display allowed for the evaluation of passive screen-mirroring in a context where users could personally dictate what they attended to, without interrupting their partner. However, this had some negative effects, namely with respect to workload and awareness as to what their partner was attending to. Moreover, the prospect of shifting control of the viewing of a device from the owner / user of the device to other inhabitants of the household brings with it significant social issues. The "acceptability of sharing" questionnaire demonstrated that, for such a system to be deemed acceptable to users, controls over when the device was to be made available to be viewed would have to be implemented, regardless of any further developments in screen-mirroring technology such as automatic privacy filtering, and regardless of whether the device is personal or shared-use with others in the household.

These findings have both short and long-term implications for how users interact with, and view, other devices in the home.

5.2.4.1 EXTENSIONS TO ACTIVE SCREEN MIRRORING

Currently, single-view TVs are the *de facto* standard in the home, with multi-view TVs reliant on technology such as active-shutter glasses which limit their uptake and adoption. As such, consideration must first be given to how screen-mirroring can be better facilitated on single-view displays. Whilst the findings indicate that passive screen-mirroring shows promise, and whilst such an approach could be designed for single-view displays, it is likely that without the ability to personally dictate what content is on the TV display, the benefits of such an approach might well be cancelled out in a single-view display.

These findings suggest that for the short term, screen-mirroring in single-view displays be further developed toward active screen-mirroring systems. This study demonstrated the utility of screen-division for both preserving existing TV content viewing, and allowing for attending to multiple content streams. However, it also demonstrated that for such solutions to be viable, TVs should be capable of aiding the user in the management of the display. For example, the TV could select which content stream to listen to, and infer focus on a given content stream based on its current activity, essentially managing audio / visual conflicts for users. With such functionality, screen-mirroring systems could be built whose capabilities go beyond that previously researched and currently available to consumers, taking advantage of large displays to share the plethora of activity ongoing in the room, if users so choose.

5.2.4.2 VIABILITY OF PASSIVE SCREEN MIRRORING

On a longer term basis, this study suggests that there is potential for a shift in how the viewing of device activity is managed. Passive screen mirroring, allowing users to selectively and personally choose to attend to activity going on within other devices in the household, shows promise, however there are significant acceptability issues that would need to be dealt with before such a system can become viable to consumers.

Beyond filtering what is on the display for privacy, there needs to be a contract between user and device that dictates when the device should make its activity available, and to whom. Additionally, this functionality needs to be simple to manage, so as not to introduce new and esoteric barriers toward shareability. A combination of geo-fencing [219] and management based on spatial context has the potential to suffice in this regard. For example, the system could ensure that activity is only made available on the home network, with the scope limited only to the room the user is currently residing, and then only if the room is used socially. Moreover, the acceptability of sharing could be inferred based on device context e.g. what application is running, or what activity is being undertaken e.g. watching a movie trailer being acceptable, whilst browsing personal email being unacceptable. This would potentially provide a simple and powerful means of managing the accessibility of device activity, but this would require future research to adequately determine. There is also the issue of awareness regarding viewing - to what extent do users want to be aware of the attention of others? In this study, one user remarked at the disconcerting nature of being unaware of the attention of their partner, suggesting that for such a system to be viable awareness of viewing needs to be improved.

5.2.4.3 APPLICABILITY TO OTHER CONTENT TYPES

In addition, the techniques demonstrated for managing the TV could equally be applied to other forms of sharing content aside from screen mirroring. For example the casting paradigm of throwing content onto the TV (e.g. a picture or video) could be supported by this system, allowing multiple content streams to be casted, with inferred management of focus preventing audio conflicts.

5.3 CONCLUSIONS AND RESEARCH QUESTION 3

Research Question 3 asked:

> Can TVs provide an awareness of others' collocated multi-screening activity without disrupting existing usage?

Experiment 4 investigated the role the TV could play in terms of making multi-screen activity (e.g. phones and tablets) shareable through the TV, demonstrating a shared screen mirroring approach whereby users could manage mirrored use of the display using an on-screen UI for requesting, taking, passing and relinquishing the TV display. This approach significantly improved a small groups ability to maintain awareness of each other's activity, by introducing the ability to selectively present this activity on the TV. However, Experiment 4 did not address the latter part of RQ 3, namely the potentially disrupting effect that such usage would have on existing TV viewing, thus rendering such a technique impractical to use alongside existing TV consumption. Experiment 5 presented extensions to shared screen-mirroring, demonstrating ways in which users capability to view and attend to multi-screen activity could be enhanced through screen-division, inferring focus, and empowering users to control their own viewing experience. These extensions improved user activity awareness, capability to collaborate and aided existing TV content consumption.

The end result was to arrive at two proposals, one for standard single-view TV displays (the inferred focus Condition), and another for multi-view TV displays (passive screen mirroring), which allowed for mirroring of multiple devices simultaneously alongside existing TV content. In traditional single-view TVs, multiple content streams could be selectively displayed, with the TV inferring focus to prevent audio conflicts, and self-organising said streams on the display. In this way, both TV and multi-screen content could be observed. In multi-view TVs, users could personally choose which content to view without disrupting others usage of the TV. In addition, the concept of having always-available devices that could be viewed on-demand by others in the room was explored, with the first steps performed exploring the acceptability of such an approach. These Experiments provide a starting point for decreasing the digital isolation that has become prevalent in multi-screen homes, by using the TV as the means by which the activity of other devices in the room can be shared and observed.

Given the results from Experiment 4 and 5, the answer to Research Question 3 is that TVs can provide an awareness of others' collocated multi-screening activity whilst minimizing the disruption to the existing TV usage of others. This was achieved for single-view TVs through screen division with inferred focus, which minimized disruption to others existing usage by both dividing the TV display to allow for multiple activities to be viewed concurrently, and pausing existing viewing when said viewing was conflicting with audio-visual mirrored activity. For multi-view displays, disruption was prevented through passive screen mirroring using a multi-view display, allowing each user to attend to whichever activity they so wished.

6. Synchronous At-A-Distance TV

The role that synchronous at-a-distance media consumption can play in the maintenance of a relationship is a significant one, with *sync-watching* [64] having been shown to bring those engaging in such activity closer together [133], engendering greater intimacy in relationships [41]. However, whilst the merits of these experiences are well known, consumer TV platforms have yet to adopt or facilitate synchronous at-a-distance usage. Accordingly, the understanding of how couples might choose to synchronously consume media and communicate in-the-wild is limited, with the majority of the literature consigned to examining behaviours in lab-based studies, or using bespoke solutions (such as asking users to manually synchronize, using Skype for communications etc.) that are poorly instrumented.

Given this, it was evident that in order to gain in-the-wild insights into at-a-distance media consumption, and demonstrate the viability of existing consumer TV platforms in being able to support such experiences, the creation of a system for communicating and consuming media synchronously at-a-distance would be necessary. Specifically, the challenge was: can synchronous at-a-distance TV experiences be facilitated using existing consumer hardware and applications, and can this be done in software-only, transparently with respect to existing consumer applications. In creating such a system, high ecological validity would be maintained, and it would demonstrate that a standardised way of providing at-a-distance experiences was not only possible, but viable for immediate implementation on an existing TV platform, with no additional hardware required and no software modifications to existing applications necessary.

In evaluating such a system in-the-wild, and instrumenting its usage and the means by which users might choose to communicate whilst using this, novel, ecologically valid insights would be garnered, going beyond prior studies which evaluated systems in lab settings, or evaluated at-a-distance consumption without the capability to instrument usage and behaviour. If proven effective at facilitating at-a-distance experiences, this would demonstrate that the barriers to providing synchronous at-a-distance TV experiences in existing smart TV systems could be practically overcome, providing significant support to co-viewing. Given this, Research Question 4 asked:

RQ 4 How can TVs support synchronous at-a-distance use with a partner?

This Chapter describes the implementation (Section 6.1) of an at-a-distance synchronous co-viewing system, called CastAway, on an existing smart TV platform, Chromecast. Experiment 6 (Section 6.2) describes the evaluation of CastAway in-the-wild by five couples at-a-distance.

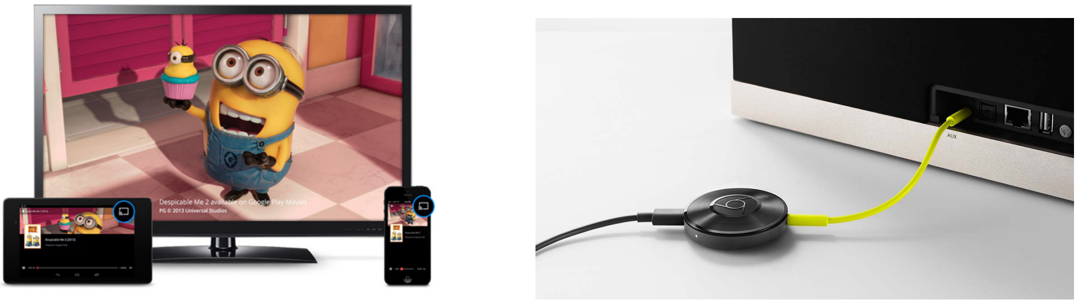
6.1 CastAway: Loosely Synchronous At-A-Distance Media Consumption

The first part of the challenge identified was to investigate whether synchronous at-a-distance TV experiences could be facilitated using existing consumer hardware and applications. A prototype was developed to this end, called CastAway, built on-top of one of the cheapest and most popular smart TV dongles currently available, Google Chromecast [68], a $30 smart TV dongle with approximately 17 million devices sold as of 2015[1].

Paired with a smartphone, a Chromecast allows for mobile applications to "cast" content to the TV screen in various forms, with support for traditional TV media (e.g. Netflix, BBC iPlayer), music (e.g. Google Play Music), games, and more. It can be connected to a TV, allowing for audio-visual output, or it can be connected to speakers for audio-only output in the case of the Chromecast Audio (see Figure 6.1). In either case, the Chromecast streams content directly from the source via the Internet, with the role of the mobile device(s) in the room that of supplying commands to the Chromecast (e.g. what to stream / play). For example, if casting a TV program, the user would typically be presented with information about the program, and the capability to pause, seek, change the volume and subtitles on their mobile device, whilst the TV performed the playback function independent of the mobile device. A user can connect to a given Chromecast from a cast-enabled application by pressing the Chromecast icon, at which point their device will retrieve session details if the cast-enabled application is already connected, or it will close the existing application and start a cast session if the application is different (e.g. switching from casting TV content to Music). In this way, multiple devices can control the same session, or start new sessions.

Given the Chromecast's innate capability for multi-user use, as well as its widespread adoption and low cost, this smart TV dongle combined with Android smartphones was chosen as

[1]http://variety.com/2015/digital/news/google-sells-17-million-1201506974/



(a) Chromecast

(b) Chromecast Audio

Figure 6.1: (a) Chromecast smart TV platform. Multiple devices can be connected, with the TV performing the media playback. (b) Chromecast audio dongle, which brings the same Internet streaming / casting functionality to existing speakers and audio systems.

the target platform, with the aim of allowing for the same user experience as is provided in shared spaces, but at-a-distance. By this it is meant that any cast commands (e.g. casting content, pausing and seeking, etc.) sent to a local Chromecast would also automatically be sent to a partner's Chromecast TV at-a-distance and *vice versa*, in effect creating a synchronous Chromecast session where the TV becomes a shared space for activity.

6.1.1 IMPLEMENTATION OF "AT-A-DISTANCE" CASTING

To enable synchronous at-a-distance casting and have it be transparent to existing Chromecast applications, rooted Android 4.4.4 phones with the Xposed framework [183] were used. This is a module designed to allow for system-level changes to the Android operating system, allowing applications to intercept any method call, replace or intercept returned objects, and fundamentally modify the behaviour of any application started on the device.

Using publicly available Chromecast API documentation, API calls and callbacks were intercepted such that CastAway could act as a man-in-the-middle between the Android application using the Chromecast, and the Chromecast library on the mobile device, acting as a proxy for the Chromecast API covering parts of the `CastAPI`, `GoogleApiClient` and `MediaRouter` APIs[2] amongst others. It is important to note that this technique was used *in lieu* of having access to the source code for the Chromecast Android library; those with access to this source code (i.e. the Google Chromecast team) could much more easily and readily intercept this functionality directly, without needing the Xposed Framework.

A companion server was also built and deployed, using a SocketIO[3] NodeJS service hosted on an Amazon Web Services (a cloud hosting platform) instance for the Android devices to forward cast activity to, such that the activity on one device could be relayed to all connected

[2]http://developer.android.com/reference/com/google/android/gms/cast/package-summary.html
[3]http://socket.io/

devices, to be executed on each user's local Chromecast in order. Only then would the appropriate callbacks be made to the client cast application. In this way, the functionality of a physically shared single-Chromecast session was recreated, but across multiple geographically separate Chromecasts. This change was transparent to Chromecast client applications, with the net effect of this being that user cast actions would be executed on all Chromecasts taking part in the CastAway session. Given the number of APIs by which applications can connect to a Chromecast, the interception of APIs was prioritized on the basis of enabling at-a-distance consumption using two applications, one for TV content (BBC iPlayer) and one for Music content (Google Play Music). Commands of relevance only to the local Chromecast (such as changing the volume, or enabling subtitles) were executed locally only. For a video of the system in use, see [4].

6.1.2 CLIENT COMMUNICATIONS

To provide a fully working proof-of-concept, a client-side application was developed both for managing when a shared Chromecast session would be initiated with a partner at-a-distance, and for communicating with a partner in such sessions, as can be seen in Figure 6.2.

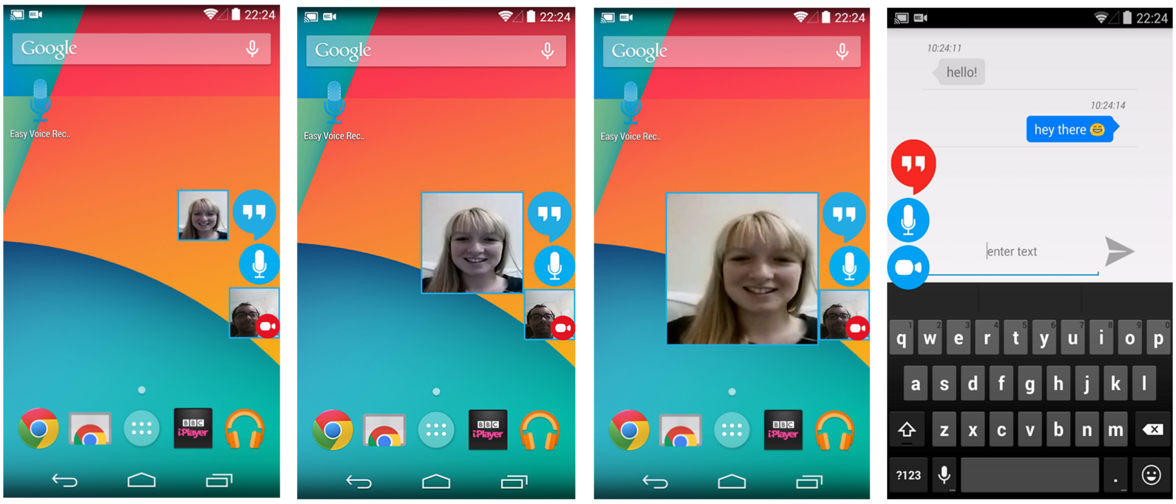


Figure 6.2: The chat UI for the CastAway system. A draggable list of 3 icons allowed users to instantly chat via text, speech, or video (and any permutation of these) to their partner when connected to a CastAway session. This chat UI was permanently overlayed on the Android device, allowing for multi-tasking with on-going communication. See supplementary video for footage of the system in use.

The application allowed for Text, Video (using the front mounted camera of the Android phone, encoded to H264) and Audio (encoded to Extra Low Delay-AAC) communications, with the functionality provided via a permanent on-screen overlay such that the chat functionality existed on top of every application. When pressing the Audio or Video buttons

[4]https://youtu.be/WPkeabY-W9A

communication was streamed in real-time to the connected partner. Reciprocal communication was not enforced, meaning that either user could use any permutation of Text, Audio, and Video without necessitating that their partner responded on the same combination of modalities. This flexibility is unusual for VMC, given that VMC is typically reciprocal and constant (e.g. a Skype video chat), however this was chosen in order to give users flexibility and allow fine-grained instrumentation of their communications - they could communicate and respond using whichever modality they wished, allowing an opportunity to examine in detail how couples chose to communicate. To emphasize immediate applicability and practicality, no additional cameras or hardware were required to use the system, with all communications mediated via the mobile devices.

A permanent notification (see Figure 6.3) provided users with the ability to mark themselves available to sync, and to see if their partner was available to sync, with audio and vibration notifications used when this state changed. When in the TV and Music applications, this notification changed to provide a limited set of functionality for managing the session, showing users what content was playing, how well synchronized their media stream was to their partner's, what application was connected, and allowing them to pause/play the media content (thereby pausing/playing for their partner also) and re-synchronize the streams if the delay became noticeable. Aside from this, no other interventions were provided regarding synchronization. The system is referred to as being "loosely synchronous" as under healthy network conditions playback synchronization remains approximately within the guidelines laid out by [62].

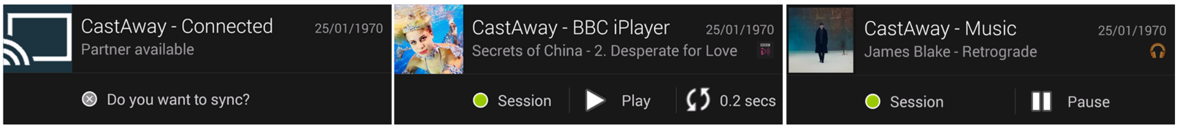


Figure 6.3: A permanent notification allowed users to see if their partner wished to start a shared session, and allowed them to control ongoing sessions, for example pausing playback, or attempting to re-synchronize streams (here a 0.2 second delay is indicated between clients). Additionally metadata (art, name, application) about what content (if any) was currently being played in the synchronous Chromecast session was also displayed.

6.2 EXPERIMENT 6 - CASTAWAY

Given that CastAway was intended to examine the feasibility of facilitating synchronous at-a-distance media consumption on consumer smart TVs, it was determined that the system should be deployed into homes as opposed to being examined in a laboratory setting. This also afforded a unique opportunity: in controlling both the communication and media functionality, the communications and behaviours of the users could be instrumented and measured. This is in contrast to prior studies which relied on self-reported measures or video annotations. Moreover, by providing two different media experiences (Music and TV), it could be examined whether different forms of media content would have the same effects and thus relevance to being consumed at-a-distance, in terms of fostering togetherness and intimacy. This allowed the testing of Research Questions regarding how the system might be appropriated, compared to what had been detailed in the literature.

Given this, Research Question 4 was expanded to ask:

RQ 4.1 To what extent would couples choose to synchronously consume TV / Music?

RQ 4.2 What effect would synchronous TV and Music consumption have on perceived togetherness and closeness on couples, compared to communicating without a shared synchronous media experience?

RQ 4.3 How would couples choose to communicate during synchronous consumption, and would this vary depending on the media type being consumed?

Automatic synchronization correction was not included in the CastAway system. Instead, users were given the capability to manually re-synchronize content streams through a single button press on a dialogue which informed them of the approximate time difference (in seconds) between the CastAway users when watching a TV program. This introduced one further Research Question:

RQ 4.4 When do users perceive the need to re-synchronize with their partner (if any)?

Maintaining client synchronization in and of itself is not problematic. However, by maintaining synchronization rigidly, an element of frustration is likely to be felt by at least one of the users. Re-synchronization necessitates that either the content being played back pauses for one viewer (whilst the other's local playback catches up), or that the content is taken back to a common time stamp (leading to one viewer re-watching content). There is significant merit in examining if/when the frustration of re-synchronization can be avoided, by allowing an element of de-synchronization. Thus, by allowing users to self-determine when re-synchronization should occur, the extent to which content playback needs to be synchronized can be examined, expanding upon [62].

6.2.1 DESIGN

For this study, 5 couples were recruited from University mailing lists (6 males, 4 females, mean age=20.9, SD=1.1, average distance apart=27.4 miles, SD=43.7 miles). All couples reported that they communicated with their at-a-distance partner daily. These couples were recruited on the basis of a number of pre-requisites: they needed to be smartphone users, familiar with VMC such as Skype, and they needed to live apart, beyond walking distance. Additionally, they were to have no visual/audio impairments. They were provided with a phone pre-loaded with the CastAway software and a Chromecast each, and given a demonstration as to how the system operated in person if available to collect the equipment from the University. In one case where this was not possible for one participant, their partner was given a demonstration whilst they were given a detailed manual. Participants were instructed that once they had the system operational in their homes, they were to familiarise themselves with both the communications and media functionality, namely the two at-a-distance applications, BBC iPlayer and Google Play Music (hereafter TV and Music).

All usage of the Chromecast and communications functions during the course of the week was recorded, allowing the measurement of the extent to which Music and TV content was consumed, what occurred in synchronous sessions and how the couples communicated in detail. For TV content, the extent to which content was synchronized was also recorded. A "Connectedness" questionnaire was also delivered to participants at three points: immediately after first usage of the communications functionality only, and again after their last usage of the TV and Music functionality. This comprised of the Affective Benefits and Costs of Communication Technologies (ABCCT) questionnaire [58] (a CSCW questionnaire examining the emotional benefits and costs of a given communications medium), and the Social Presence factor from [133] (SP1–4, 6, and 7). A post-study questionnaire also asked questions regarding user experience of social TV (perceived usefulness, attitude, and intention to use) from [194], emotional connection from [58], synchronization from [62], and engagement / togetherness from [104]. Participants were interviewed after the study using questions derived from [41] regarding preferences and the effect that using the system had on their relationship over the week. See Appendix I for experimental materials (question set and plain language statement given to participants).

6.2.2 RESULTS

Unless otherwise stated, for parametric tests a repeated measures ANOVA was performed using *lme()* in *R* as prescribed by [57], with likelihood ratios reported, and *post hoc* Tukey contrasts performed where applicable. For non-parametric tests a Friedman's ANOVA was performed using *friedman.test()* in *R*, with *post hoc* pairwise Wilcoxon Rank Sum Tests performed where applicable.

6.2.2.1 HOW WERE SESSIONS INITIATED, AND WHAT MEDIA WERE CONSUMED? (RQ 4.1)

On the initiation of a CastAway session, both partners were prompted with an optional question asking how the session had been arranged. Sessions were predominantly initiated on an *ad hoc* basis or scheduled on the day, as can be seen in Figure 6.4.

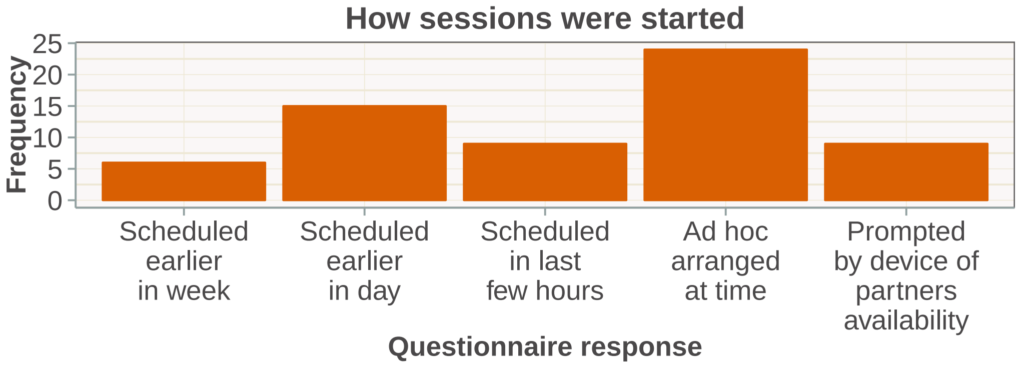


Figure 6.4: How CastAway sessions were initiated across participants (optional, with question delivered at the beginning of each session for both participants).

There was one "other" response, which indicated a restart of a previous session, and one differing response between the pair, where one partner believed the session to have been scheduled earlier in the day, whilst the other partner believed it to be *ad hoc*.

A breakdown of what media was consumed over the course of the week can be seen in Figures 6.5 and 6.6, with usage shown by Comms. (communications only, being conducted at the start of the study as a baseline when not consuming media synchronously), Music, TV and Mixed (Music and TV in the same session). Sessions lasted on average for 30 minutes when consuming Music, 77 minutes when consuming TV content, and 46 minutes when mixing TV/Music.

In terms of frequency and duration of sessions, in a RM-ANOVA there was no significant difference by frequency $\chi^2(3) = 4.46, p = 0.22$, however there was a significant difference by mean duration $\chi^2(3) = 10.32, p = 0.02$, with *post hoc* Tukey's tests showing a significant difference between TV and Comms, as can be seen in Figure 6.5. Synchronous casting sessions tended to last for a minimum of approximately 30 minutes, meaning that users engaged with the system and did so on multiple occasions.

In terms of total duration of consumption, as can be seen in Figure 6.6, TV was the dominant media consumed. In a RM-ANOVA there was a significant difference $\chi^2(3) = 11.22, p = 0.01$ with *post hoc* Tukey's tests showing significant differences between TV and Music / Mixed / Comms. Across groups over the course of the week the mean total duration of TV was 4h:24m (SD=3h:52m), greater than both Music (49m) and mixed sessions (1h:14m). In terms of playback of content during these sessions, each group on average viewed 7 TV programs (SD=7.71) with TV programs typically over half an hour in duration, meaning there

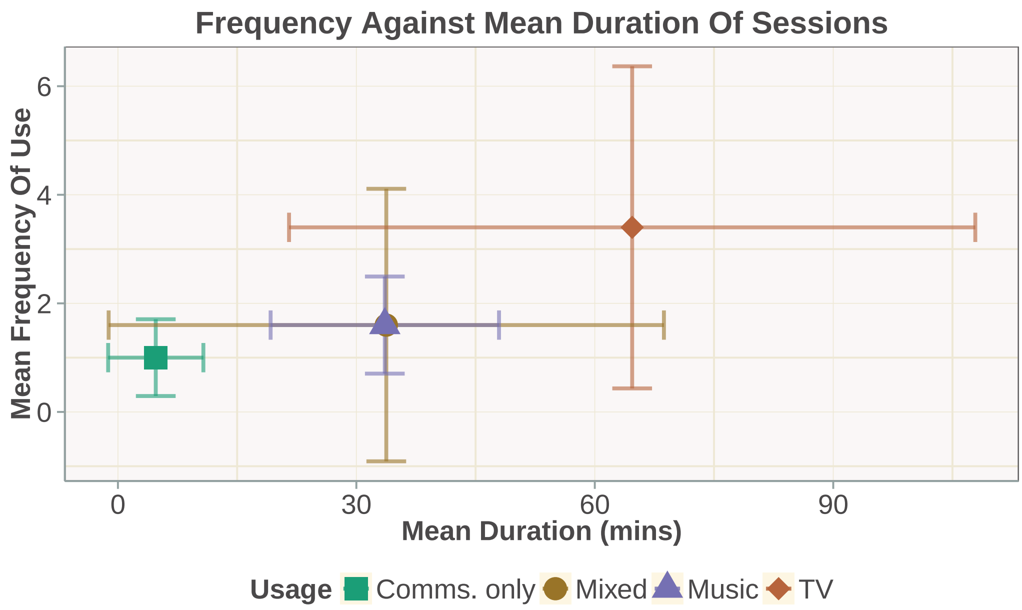


Figure 6.5: CastAway sessions by media being consumed in said session, by frequency of occurrence and mean duration of session. Usage is shown by: Comms (communications only, no media), Music, TV and Mixed (Music and TV in the same session). Error bars show standard deviation.

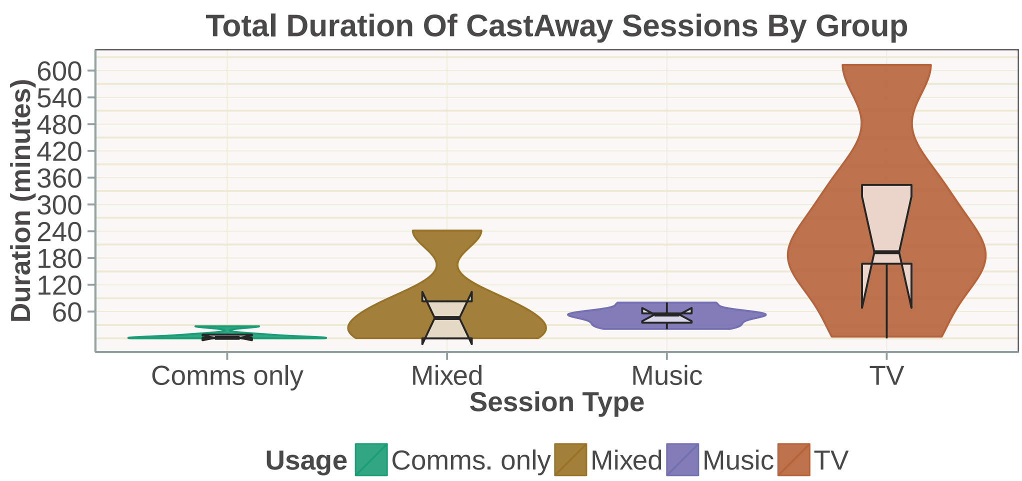


Figure 6.6: Total duration of usage of CastAway by groups: Comms (communications only, no media), Music, TV and Mixed (Music and TV in the same session).

were no short-form videos viewed (average TV program duration=48m:52s, SD=16m:53s). For Music, there were on average 19 music tracks/playlists played back (SD=12.05).

6.2.2.2 HOW SYNCHRONIZED WERE THE COUPLES? (RQ 4.4)

With respect to quantifying the synchronization experienced by clients, perceived synchronization was captured via questionnaire, re-synchronization events (where a user requested that playback be synchronized to a common prior time stamp via the session management notification) were logged, and real-time data regarding media playback synchronization recorded. However, in the latter case, this could only be done for TV playback, and not Music, due to limitations in what was accessible from the Music application.

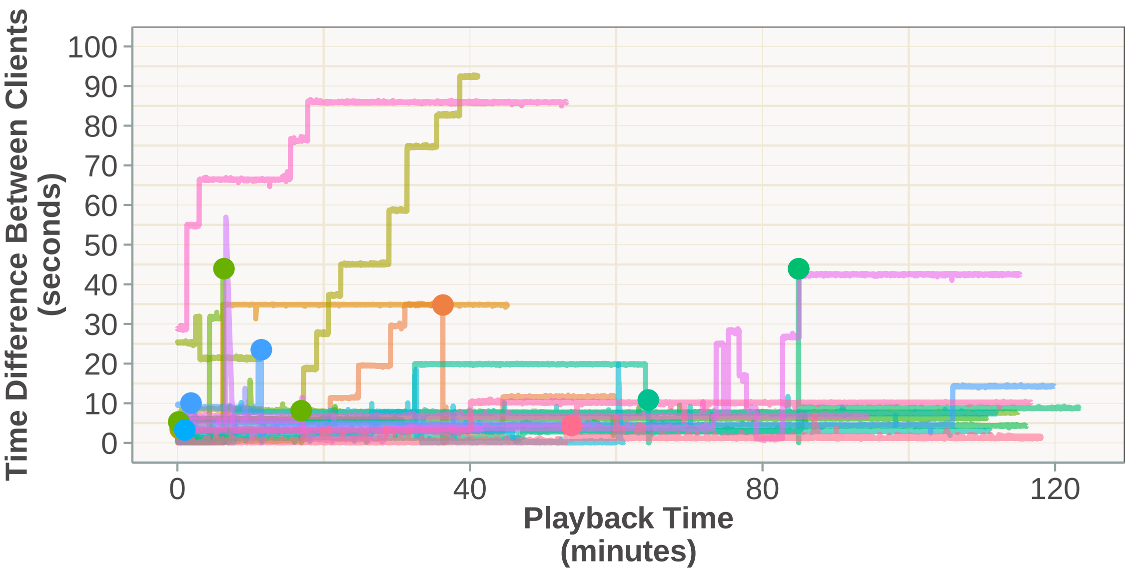


Figure 6.7: Synchronization against playback time for TV content. Each colour represents a separate TV playback instance, with coloured dots indicating user-issued "re-synchronization" commands.

TV synchronization varied during the course of the study due to fluctuations in the quality of internet connectivity at the participants' households. As can be seen in Figure 6.7, the re-synchronization function was used by users only 12 times over the course of the study (across 26 TV playback instances), with groups using the function 2.4 times (SD=2.19) on average over the course of the week. This limited use is surprising considering that mean synchronization for TV playback was 11.04 seconds (SD=19.85), exceeding the guidelines set out by [62]. Excluding uses of the re-synchronization function that were likely users exploring the functionality of the system (of which there were 5 occasions, at the start of playback when there was little-to-no de-synchronization) 5 of the remaining 7 uses occurred when the time difference between participants exceeded 10 seconds. There were however 7 playback instances where significant delays (ranging from 8 seconds to approximately 100 seconds) were tolerated without re-synchronization.

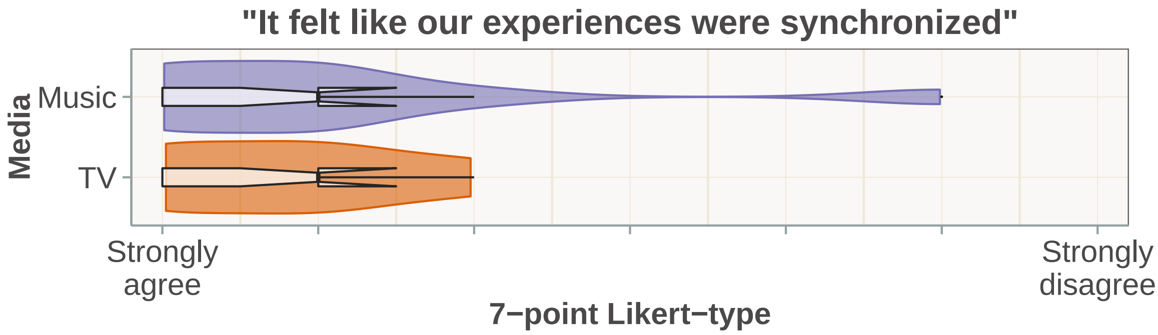


Figure 6.8: Perceived synchronization across TV and Music. A Friedman's test showed no significant difference $\chi^2(1) = 0.34, p = 0.56$ between TV and Music.

Regarding perceived synchronization (see Figure 6.8) there was no significant difference between TV and music content, with participants strongly agreeing that both appeared synchronized.

6.2.2.3 HOW DID THE COUPLES COMMUNICATE DURING CONSUMPTION? (RQ 4.3)

For communication, each permutation of Text, Audio and Video was examined exclusively, meaning that, for example, Audio refers to only the audio channel being used exclusively, not including permutations such as Audio-Video. Text refers to the text chat dialogue being open on the mobile device; Audio refers to the participant broadcasting the phone microphone to their partner, whilst Video refers to the participant broadcasting the view of the front-mounted camera on their phone to their partner. This communication was not coupled, i.e. participants could independently choose which channels they wished to broadcast their communications over, out of Text, Audio and Video, but had no control over which channels they received from their partner (aside from leaving the session, locking their phone, or muting their phone using the volume controls).

With respect to how couples communicated over the 5 cumulative weeks of usage, Text largely dominated across both TV and Music media types. For total duration of usage across groups (see Figure 6.9) a two-way RM-ANOVA treating communications channel (all permutations of Text, Audio and Video) and media type (TV, Music and Communications only) as factors showed there was a significant main effect on communications channel $F(6, 108) = 5.03, p < 0.01$ with *post hoc* Tukey's tests showing significant differences between Text only and Audio only, Video only, Text+Audio, Text+Video, Audio+Video, and Text+Audio+Video, and an interaction effect $F(6, 108) = 2.30, p < 0.05$.

For frequency of usage (see Figure 6.10), a two-way RM-ANOVA was again performed treating communications channel and media type as factors. This showed a significant main effect

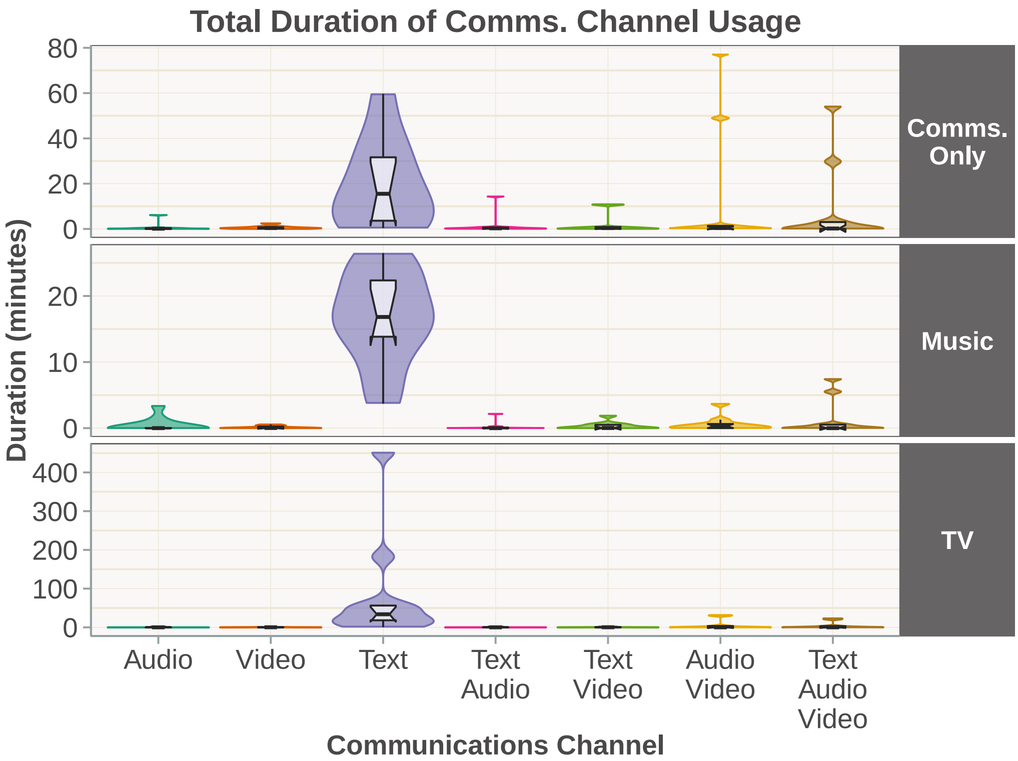


Figure 6.9: Total duration of communications instances across groups by media type.

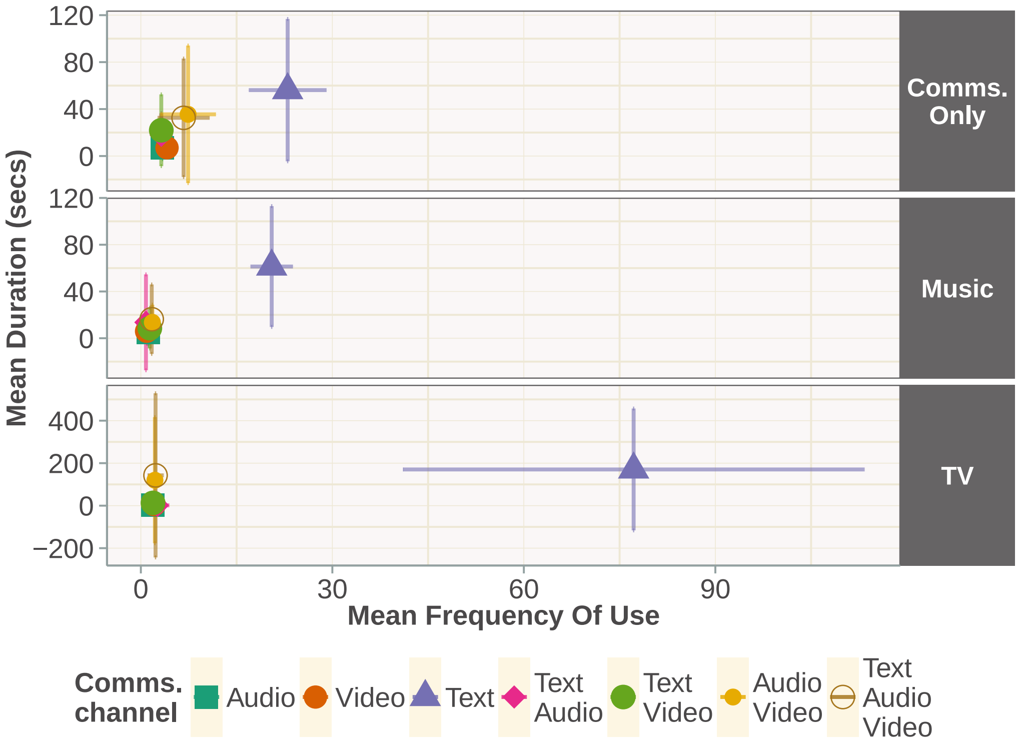


Figure 6.10: Mean duration and frequency of occurrence of communications instances across groups by media type. Error bars show standard deviations.

on communications channel $F(6, 108) = 6.74, p < 0.01$ with *post hoc* Tukey's tests showing significant differences between Text only and Audio, Video, Text+Audio, Text+Video, Audio+Video, and Text+Audio+Video, and an interaction effect $F(6, 108) = 2.37, p < 0.05$. For duration of usage there were no significant main or interaction effects. The duration of a given communication instance remained largely the same, with communication channels remaining open for relatively short periods (under a minute) when consuming Music and for longer periods (under 3 minutes) when consuming TV.

Normalizing the total duration of communications by the total duration of usage of the system (see Figure 6.11), it can be seen that the amount of communication per minute of usage was largely the same between TV and Music, with Text chat constituting approximately 20 seconds out of every minute of usage of the system. In a two-way RM-ANOVA there was a significant main effect on communications channel $F(6, 108) = 21.525, p < 0.01$ with *post hoc* Tukey's tests showing significant differences between Text only and Audio, Video, Text+Audio, Text+Video, Audio+Video, and Text+Audio+Video. Whilst Text chat occurred more often in Music, this difference was not statistically significant (media type factor: $F(1, 9) = 0.35, p = 0.57$).

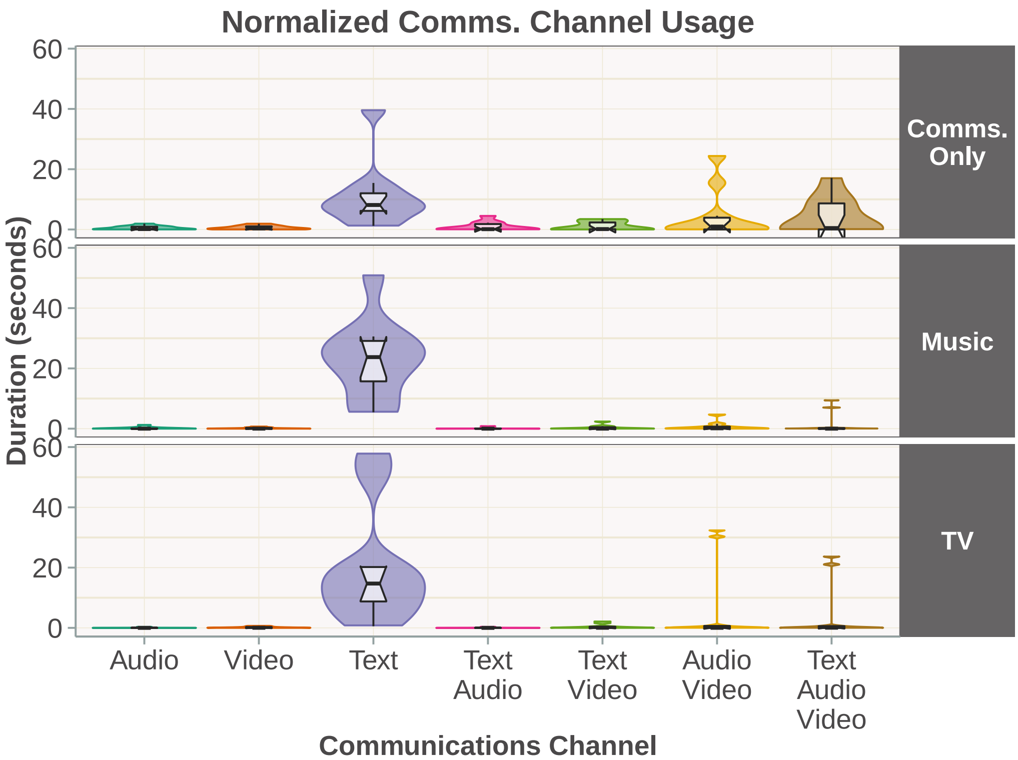


Figure 6.11: Normalized usage of communications functionality per minute of system usage, $y = Total\ Usage\ of\ Comms.\ Channel\ (in\ seconds) \div Total\ Consumption\ of\ Media\ Type\ (in\ minutes)$.

In four of the five groups, Text chat was the predominant form of communication utilized, regardless of the media being consumed. The exception to this behaviour was Group A, where in 3 of their 4 CastAway sessions they relied upon Audio-Video / Text-Audio-Video for communications. For the Text-dominated groups, Text dialogs typically did not remain open throughout consumption, instead being opened and closed as required, indicative of multi-tasking behaviour on the devices. Text messaging occurred throughout consumption in all groups.

For the Text-dominated groups there were, however, short intervals when users elevated or augmented text conversations using Audio or Video communication. There were 12 occasions where participants in groups B–E utilized VMC for short intervals (4 Text-Audio, 2 Text-Video, 2 Audio-Video and 4 Text-Audio-Video). Of these, 5 uses occurred prior to / at the start of content playback, 4 uses occurred at the end of the content playback, and 3 occurred during consumption. An example of this behaviour can be seen in Figure 6.12.

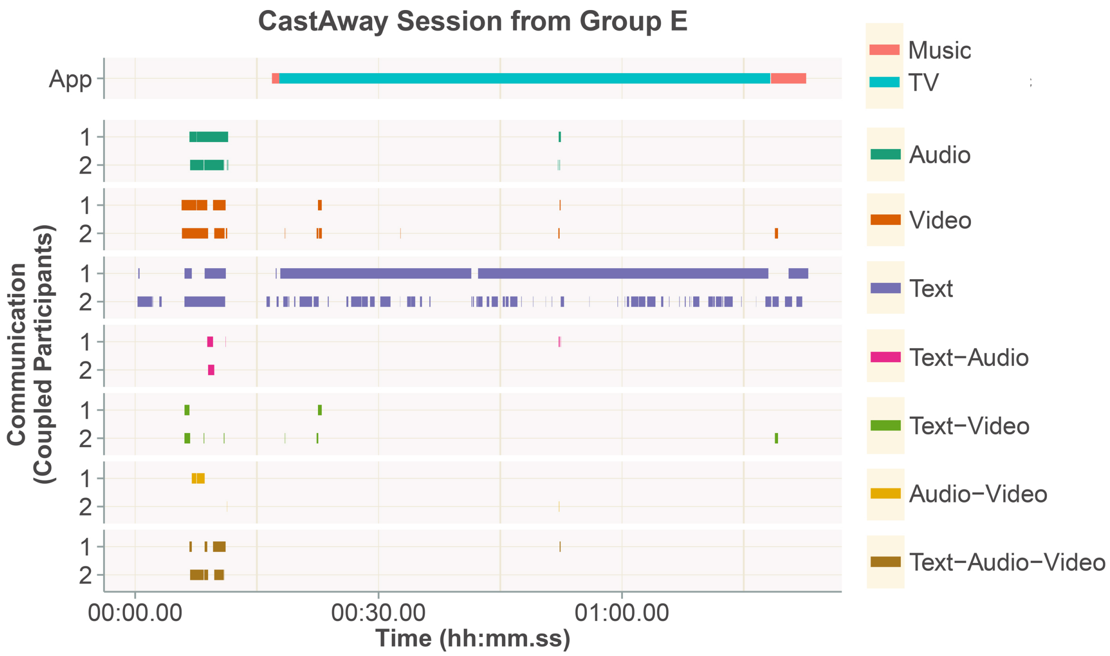


Figure 6.12: CastAway session from Group E. The session lasts approximately 90 minutes, with both TV and Music consumed. Prior to the TV consumption, there is approximately 5 minutes of communication by both participants across the available Text/Audio/Video modalities, with shorter Text–Audio and Text–Video events also occurring during consumption.

6.2.2.4 Effect of TV and Music Consumption Compared To Communications Only (RQ 4.2)

The ABCCT questionnaire [58] was used to compare Communications only against TV and Music usage. There was a significant effect on the Emotional Expressiveness subscale, however there was no significant difference in *post hoc* tests. This suggests that consuming Music whilst communicating may inhibit expressiveness to some degree, but does not confirm that this is the case. There were no significant differences on any of the other subscales (see Figure 6.13), with communication during TV and Music consumption seen as broadly comparable to communicating without a synchronous shared experience.

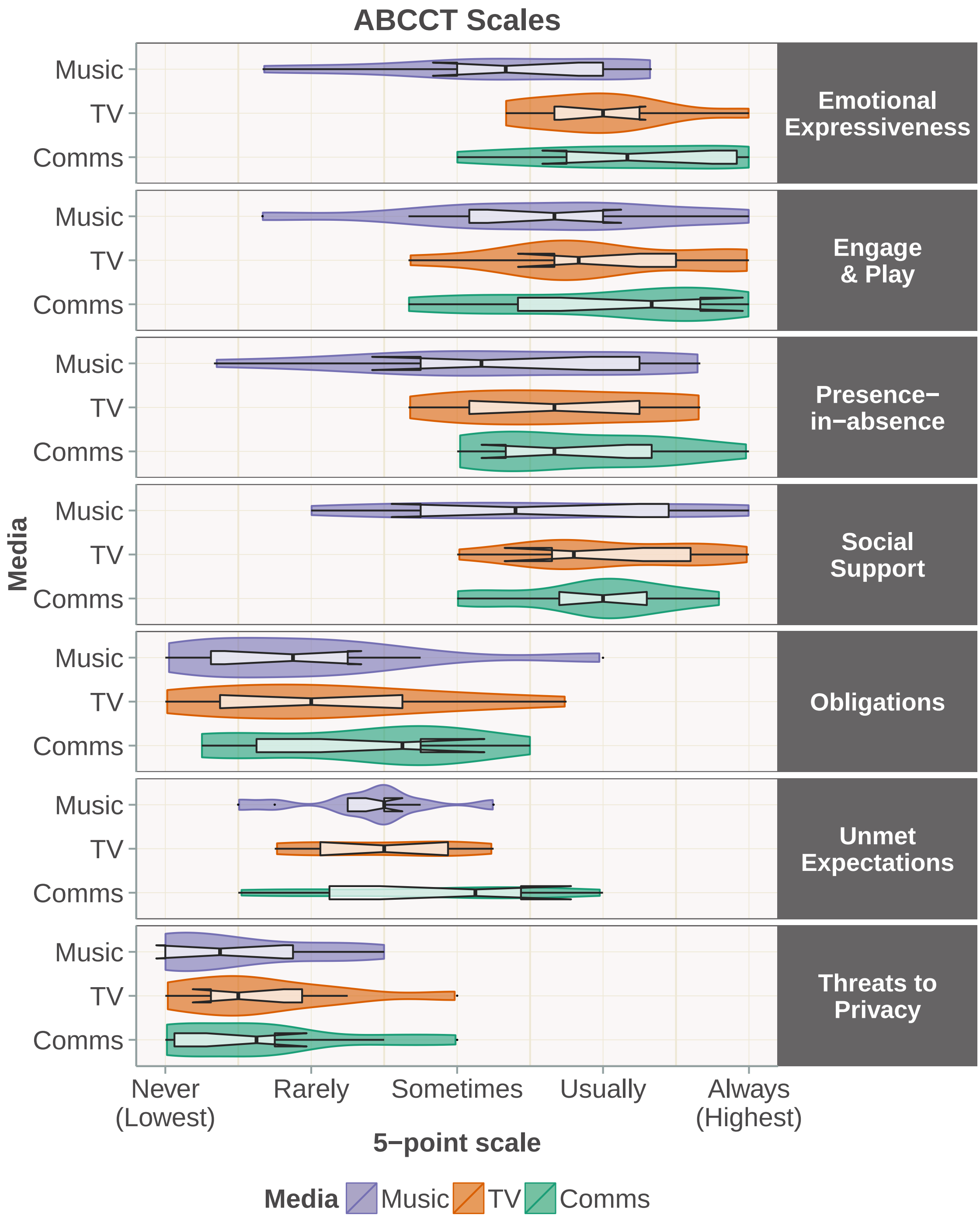


Figure 6.13: Affective Benefits and Costs of Communication Technologies (ABCCT) [58]. Friedman's test results – **Emotional Expressiveness**: $\chi^2(2) = 6.7, p < 0.05$, *post hoc* Wilcox: No significant differences. **Engage and Play**: $\chi^2(2) = 0.19, p = 0.9$. **Presence-in-absence**: $\chi^2(2) = 0.21, p = 0.9$. **Social Support**: $\chi^2(2) = 0.38, p = 0.8$. **Obligations**: $\chi^2(2) = 3.3, p = 0.2$. **Unmet Expectations**: $\chi^2(2) = 3.3, p = 0.2$. **Threats to Privacy**: $\chi^2(2) = 1.7, p = 0.4$.

With respect to Social Presence (using the social presence factor from [133]) there was no significant difference for social presence across media types. However, for Closeness ("[Using the devices to communicate / Listening to music together / Watching TV together] made me feel closer to my remote companion") consuming TV together was significantly perceived as helping participants feel closer to their partner compared to Communications only (see Figure 6.14). These results confirm that in having a shared experience occurring alongside communication, users feel closer to those they are communicating with.

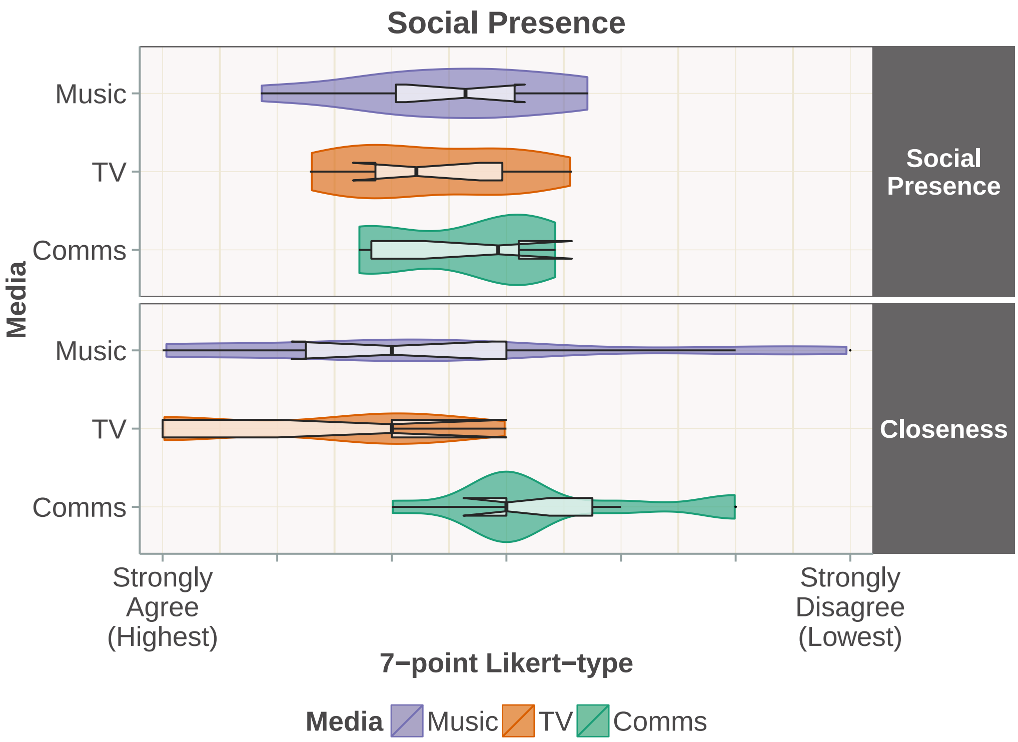


Figure 6.14: Social Presence and Closeness from [133]. Friedman's test results – **Social Presence**: $\chi^2(2) = 2.8, p = 0.2$. **Closeness**: $\chi^2(2) = 10, p < 0.01$, *post hoc* Wilcox: Significant difference between *TV* and *Communications Only*.

Examining the CastAway system more generally, participants were asked to rate the extent to which using the CastAway system affected the couples' communications over the course of the week. Having use of this system improved couple's perceived frequency, duration and quality of communications as can be seen in Figure 6.15. Whilst this perceived improvement was modest, this nonetheless underscores that at-a-distance media consumption can have a meaningful effect on relationship maintenance.

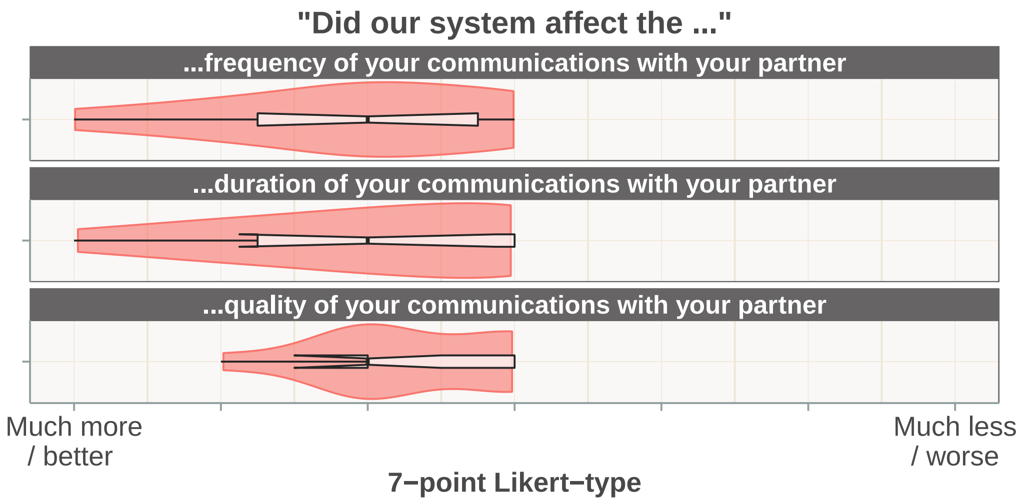


Figure 6.15: Responses to frequency, duration and quality of communication questions [58]

6.2.2.5 End of Study Completion Questionnaire Contrasting Music and TV (RQ 4.2)

Couples were asked to complete questionnaires examining togetherness / connectedness and their experience of social TV (e.g. in terms of intention to use in the future, usefulness, etc), for both media types (TV and Music). This was done in order to establish couples perceived differences between TV and Music when consumed at-a-distance with respect to usage and experience.

As can be seen in Figure 6.16, there were no significant differences between Music and TV, and their mean ratings were better than neutral, suggesting they both improve togetherness, increase the perception of experiencing activity with the at-a-distance partner, and increase engagement. However, Music typically exhibits a long tail, indicative that the perceived effect of Music consumption was not universal across couples.

This trend continues in Figure 6.17. Again, there were no significant differences between TV and Music, with both having mean ratings better than neutral across scales. However, the long tail of Music is still prevalent.

6.2.2.6 Post-Study Interview

At the end of the study, couples were interviewed together about their experience using the system. Interviews were loosely guided, with a core set of questions followed by deeper probing where an interesting line of inquiry was identified. At the end of the interviews, participants were offered the chance to provide any thoughts or opinions that they felt had not been captured by the interviewer. The core questions examined what effect the system had

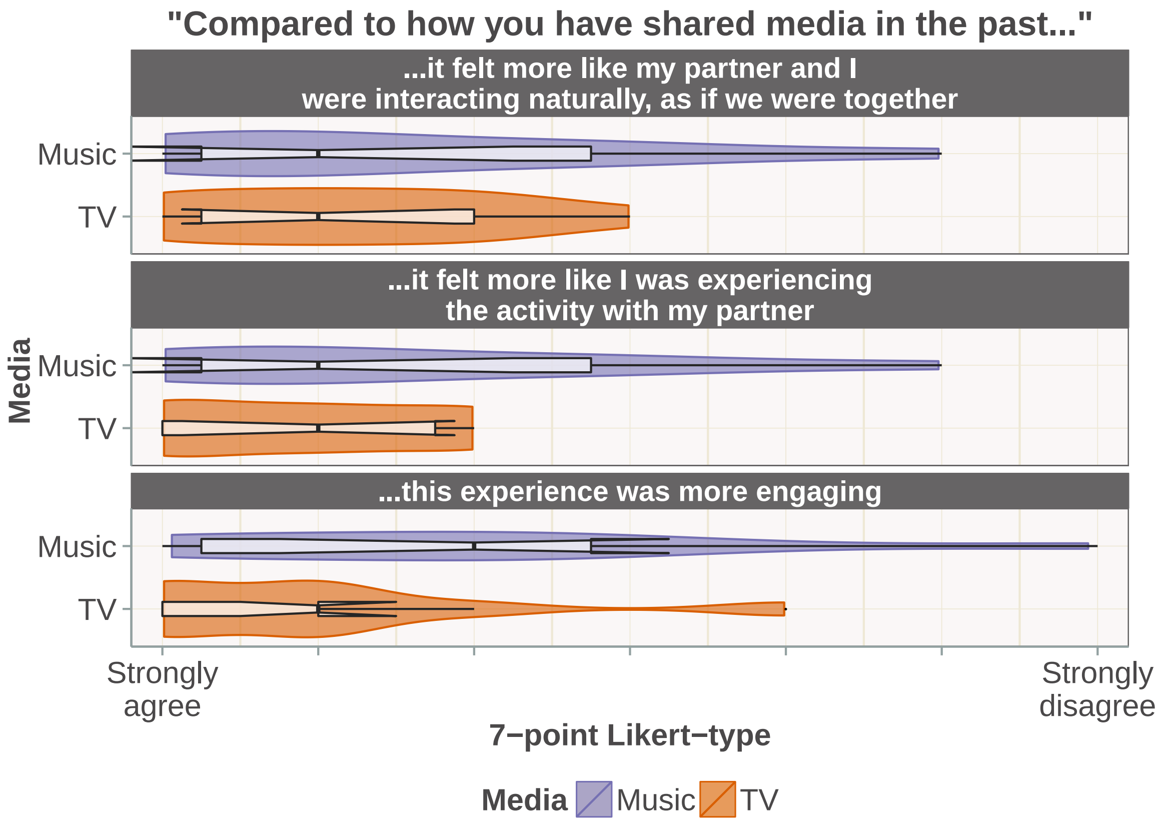


Figure 6.16: Responses to "Compared to how you have shared media in the past..." [104]. Friedman's test results – **As if we were together**: $\chi^2(1) = 0, p = 1.0$. **Experiencing activity**: $\chi^2(1) = 0.67, p = 0.4$. **Engagement**: $\chi^2(1) = 0.67, p = 0.4$.

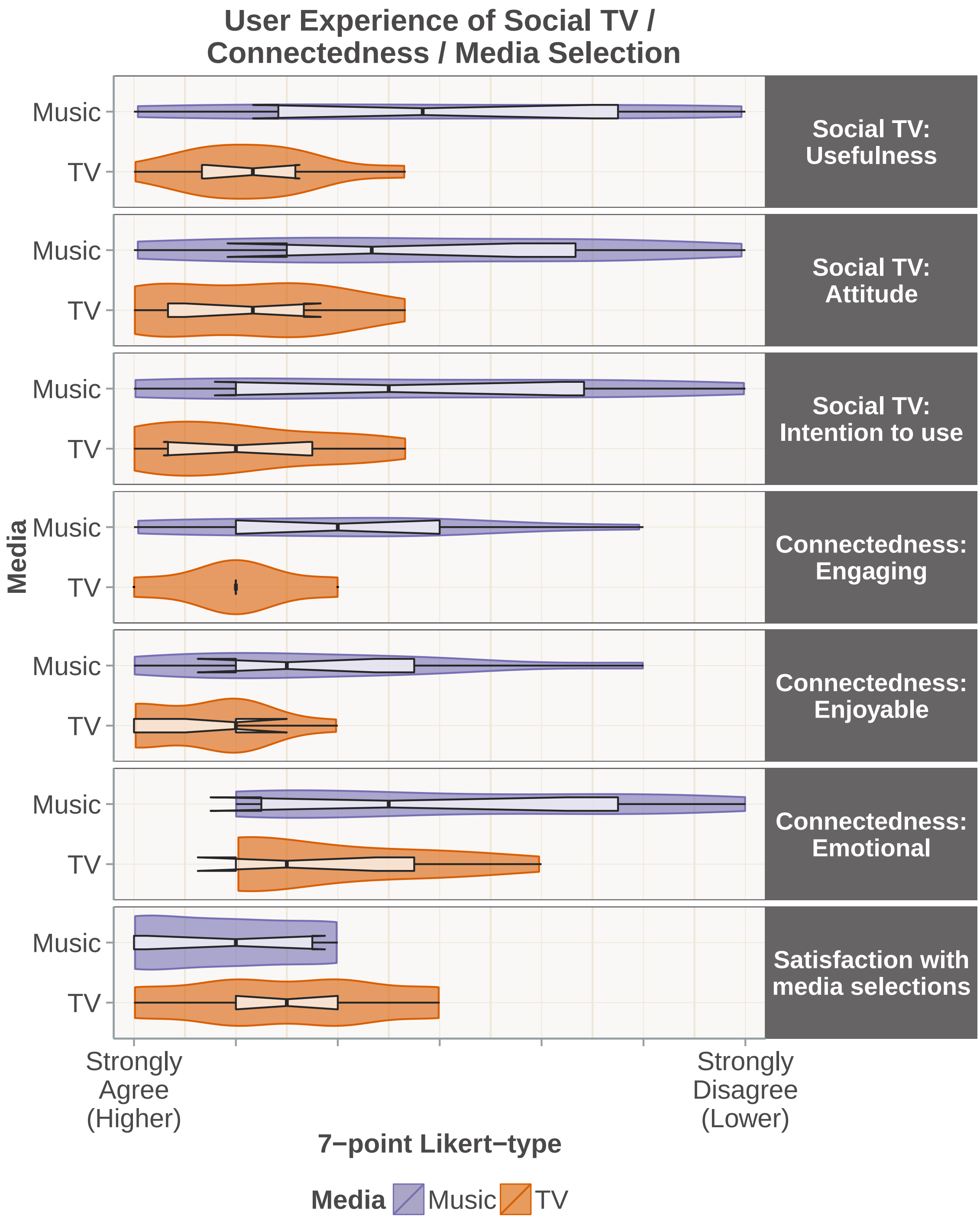


Figure 6.17: User Experience of Social TV [194] / Connectedness [62]. Friedman's test results – **Usefulness**: $\chi^2(1) = 2.8, p = 0.1$. **Attitude**: $\chi^2(1) = 2.0, p = 0.2$. **Intention to use**: $\chi^2(1) = 1.0, p = 0.3$. **Engaging**: $\chi^2(1) = 1.3, p = 0.3$. **Enjoyable**: $\chi^2(1) = 2.7, p = 0.1$. **Emotional**: $\chi^2(1) = 4.0, p = 0.05$. **Satisfaction with media selections**: $\chi^2(1) = 1.3, p = 0.3$.

on their relationship, preferences regarding TV and Music use and media selection, closeness / togetherness, and whether the system was a burden or perceived as being intrusive.

Excerpts from the interviews have been grouped into related discussion themes then broken down by couple (denoted by line separators). These themes were *Attitudes Toward CastAway*, *Attitudes Toward TV* and *Attitudes Toward Music* addressing RQ 4.1; *Role of TV and Music* and *Effects of Usage* addressing RQ 4.2; *Attitudes Toward Communication Modality* addressing RQ 4.3 and *Content Synchronization* addressing RQ 4.4. *I:* refers to the interviewer with *P#* referring to a given participant by number, *P1–2* belonging to Group A, *P9–10* belonging to Group E.

ATTITUDES TOWARD CASTAWAY (RQ 4.1) The system proved popular with all the couples interviewed, with all five couples expressing an interest in using it further:

> *P2*: I really liked it, I thought. I would use it long term, to be honest.
> *P1*: I enjoyed it. I think I'll miss it!

> *P4*: Overall I really enjoyed the experience – it was fun and new and something I would never have tried.

> *P5*: I just think it's really good, I think if it were available it'd probably be something I would use.
> *P6*: See if you had the Chromecasts and were just using our own phones, then I would definitely use that, and we'd keep doing it.

> *P7*: I would use the system.
> *P8*: Yeah, with more options [TV content] it would be better.

> *P9*: We liked it.
> *P10*: We would use it. Last year we were both on years abroad, and we tried sometimes to do that, but have [the] Skype app [connected] and watch something at the same time. But we'd always have problems, like someone's internet wouldn't work, or it would be out of sync and... it was more hassle than it's worth. But with something like this it would have been really good.
> *P9*: And also our laptops would be really slow, because you'd be running the TV program or whatever and also have Skype in the background, and it wouldn't really work. The fact this was all in one kind of made it a lot easier.

However, for one couple, use of the system did exacerbate feelings of separation:

> *P5*: It kind of made you more aware of the fact that you weren't just sitting watching TV together [in person]. But it was nice, it felt that you were making time for each other, sitting down and watching something together.
> *I*: Did it make it worse at all that you were being reminded that you weren't in the same space?
> *P6*: At times yeah.
> *P5*: Sometimes yeah.
> *P6*: When we were watching that we're really enjoying, and having proper conversations about it, it kind of reminded you that it'd be nice if you were actually together.
> *P5*: But I suppose you don't have any other option. It's not as good as actually sitting together watching something, but it's better than watching stuff at different times and talking about it later.

ATTITUDES TOWARD TV (RQ 4.1) TV also proved universally popular with the couples, with the caveat from two couples that additional content beyond what was available via BBC iPlayer would be preferable:

> *I*: Did you find that having the TV made you feel closer to your partner?
> *P1*: We watched TV and then he was like "aww this is happening" but we were in sync, so I could see what was happening at the same time. So that was good, because we could talk to each other whilst something was going on on TV.

> *P3*: That was something that I would definitely see both of us using, because we've tried to do that in the past without an app to do it. It's definitely good to have that thing for that purpose, and having that would probably help you do it more often.
> *P4*: I really liked the synchronised TV - we watch a lot of programmes together and often I need to wait until we are together to do that. I feel this solved it. I would definitely use this system a lot.

> *P5*: We talk about TV, but we'd talk about it after as we'd watch it at different times.
> *P6*: But it's easier to sit and talk about it if you're watching it at the same time, like if he was to laugh at something I'd know exactly what he's laughing at,

rather than a whole paragraph to explain, because we were watching at different times.
P5: It'd be good if we could have had Netflix or something as well obviously.

P7: I did like that, I thought it was good.
P8: Only if it was more than BBC iPlayer, because we ended up having to watch things we wouldn't normally watch

P9: For that I think it was perfect. It's things we would do anyway, we would both watch a tv program, maybe not necessarily at the same time, but to do it at the same time with someone else.
P10: And then to be able to have like messaging and stuff where you can talk about it.
P9: Or see the other persons face while they were watching it. Yeah, I think it's a really good idea.

Media selections were discussed immediately prior to viewing for two couples, with one couple (Group A) having selections made explicitly by the lead partner due to a conflict in media preferences, and two other couples (Groups B and C) taking turns:

P1: He picked the programs for TV, because he's fussy.

P3: We basically picked on different nights, who would watch what.

P5: [We would] see who wants to watch something. There were times where we knew we'd be able to watch TV together where we both looked on iPlayer to see if there was anything we fancied watching.
P6: It was more planning what time to do it, and then finding something then. I was going to suggest something, then the next night you suggested what to put on.

P8: We spoke over the text about what to put on really.

P10: I'd say with the TV we just looked at what the options were
P9: Yeah, we discussed what we wanted to watch while we were choosing.

ATTITUDES TOWARD MUSIC (RQ 4.1) Two couples were positive about consuming Music at-a-distance, and relied upon the Music functionality heavily:

> *I*: Did you have a preference between the TV and the music, in terms of what you enjoyed consuming together more?
> *P2*: Probably music
> *P1*: (At same time) Music probably, yeah, because we could be doing other things and then music would be playing and we could still talk to each other, whereas TV, like, I have very different tastes in TV than he does, and because it was BBC iPlayer, but we found a couple of things, so that was ok. I think if you had Netflix or something, that would be good, so if you could watch a full movie.
> *P2*: I quite liked watching TV, but... the music was really good, because you were showing me songs that I'd never heard before, like songs you'd been listening to on Spotify, because you use Spotify and I don't, so like songs that [my partner] had heard and said "you'll like this", and then we were listening to songs we had listened to years ago and hadn't heard in ages, just for a laugh and stuff, cheesy songs.

> *P7*: That [Music] was good, because normally if we're sitting studying in our own houses, we're not really connected. But allowing us to listen to the same music at the same time helped make us feel closer.
> *P8*: And speaking about the same kind of music.
> *I*: Did your tastes in music differ?
> *P8*: He put Westlife on for me for a wee bit!
> *P7*: There's music I like and music you like, and there's music we both like, so we just stuck that on.
> *P8*: We know what bands we both like.

In contrast, for the remaining three couples opinions on Music were mixed or negative, each for a different reason. For Group B, Music was a medium that needed to be consumed in person. For one partner specifically (P3) Music demanded a higher level of engagement, which was not suited to communicating via the provided phones. For Group C, music tastes differed to the extent that there was a lack of common ground between the pair when it came to selecting what to listen to. For Group E, Music was personal, with participants preferring to experience it individually:

> *P3*: I liked it because it's always good to be able to listen to music with someone else, but it's not the same as sitting down and putting on a CD with the person

with you. It has advantages but it wasn't the kind of thing that I'd plan to do, I don't think I'd ever say lets put on this album and listen to it over the system, we'd meet up and do that. And I don't think it's something we would spontaneously do, you'd probably send a link to the video for the song instead. I liked the fact you can do that, but I don't know if I'd use it. When it's Music you want to have a proper conversation about it, which is a bit more difficult over a longer distance.
P4: I don't think the synchronised music was very good - I don't see a time I would ever use it. Maybe if we were both getting ready to go out but even then I think we would just play our own music. It was fun to pick songs that one time but I don't think I'd use it again.

P6: Disliked it.
P5: Yeah, the only times we'd listen to music together would be when we were going out.
P6: Our music taste differs a bit from our TV taste, so when we did do it, it was songs we both liked, but we weren't totally into it because our music differs.
P5: Most of the music I would listen to is not the kind of music you'd sit down and listen to together.
I: Would you say your tastes in TV are closer in that case?
P6: Yeah

P10: I didn't like the music as much, but I feel like we probably wouldn't use it.
P9: We don't really listen to music together that often.
P10: I guess it depends on the person. Like I think music is quite a personal thing.
P9: I would agree with that, it's maybe the way our relationship is.
I: Would you say you have similar or divergent tastes in music?
P9: Similar. I don't think it's to do with the tastes, I think it's just that I don't listen to music with other people anyway, it's a thing I do to relax.
P10: And then I guess that's not necessarily at the same time that I would want to listen.
P9: Television or films made more sense. It's more of a community based thing.

ROLE OF TV AND MUSIC (RQ 4.2) However, for the two couples that were positive about Music, it was used both as a background activity to a secondary task, and as a means to form a connection whilst requiring less attention or engagement than TV:

P1: We could be doing other things and then music would be playing and we could still talk to each other. I came home from work and I was just lying in bed being lazy, and he just put songs up and I was like "yeah, this is good", and I'd just sit there, not doing anything, just listening... we could be doing other things and then music would be playing and we could still talk to each other.

P8: You could walk away from it and come back in and talk about it again. Music is more... walking about.
P7: Yeah, you could just have it on in the background almost.
I: Is that what you used the music for?
P7: Music was more when we were doing stuff.
P8: I was tidying my room and stuff, and I could just hear the music playing through the TV.
P7: I think that's the nice thing, that's why it's good. With the music it brings you closer.

Conversely, TV was a sit-down activity for all our couples, demanding more attention than Music. As a consequence, for one couple, this led to a case of "Butler lies" [83], text-based deception:

P2: We sat down to watch it
P1: We both sat down to watch it.
I: So you didn't have it just playing in the background?
P1: No, we just sat down to watch it, and spoke to each other while it was on. Depends what it is though, if it's something I'm interested in, I will watch it, but if it's something I'm not interested in, I'll tell him I'm watching it, but I won't watch it! (laughter)
P2: The other one I think I was just kinda watching and you really weren't.
P1: Was that the comedy one? I don't like comedy. But I was watching it, but I was also talking to you at the same time, I wasn't doing anything else.
P2: You kept talking to me, and I was kinda ignoring you a wee bit, because I was watching it. (laughter)

ATTITUDES TOWARD COMMUNICATION MODALITY (RQ 4.3) With respect to communication, text communication was preferred by four of the five couples:

I: What did you prefer out of the different ways you had to chat to each other?
P1: The audio, and the video.

P3: Yeah, the [Text] messaging was the one we used the most, just because the video was quite small and again if you're watching something, you don't want to have a video up of someone else most of the time. And if you were going to video someone you'd use a different application to do that.

P6: Text
P5: We used Text, we tried them all, but we didn't use any except text, when you're trying to watch something [it was better].
I: Was there any reason you preferred text?
P5: We don't really chat on the phone that much, because we're both quite busy. Especially if you're watching something.
P6: Just using the text option fitted with us, and what we do. I think if we went out of our way to do phone calls, we wouldn't have enjoyed it as much.

P7: It was easier, we were more constantly texting, but we were sometimes talking over video depending on what we were doing.

P9: Text.
P10: Text mainly.
P9: I don't think we used audio at all.
P10: Only a little bit at the start.
P9: To discuss what we wanted to talk about. But when you're watching a TV program you've already got a visual element and a vocal element, so the text was perfect.

This preference toward text communication over permutations of text, audio and video communication appeared to be an explicit choice regarding the suitability of the communication medium to being used whilst consuming TV and Music, rather than a deficiency in the way video/audio communication was enabled, with 4 groups commenting on how our implementation of video chat was preferable to existing implementations:

P2: They were quite good, because you could make [the video] as big or small as you want.
P1: For just talking to each other, it was a lot easier than using Skype or any of those things.
P2: Aye, it was so much quicker to just connect everything.

> *P1*: And you could have the audio, or the video, I could leave the phone on my bed and walk about the room while he's still talking to me, and do other things.
> *P2*: I never really got into Skype or anything like that.
> *P1*: We tried Facebook video and we didn't like it either.
> *P2*: I don't know why we didn't like it, because in theory they are all the same, but it just kinda felt right. It was good to be able to see each other and talk, and have a background. You know you can minimize the chat, so you can do something in the background.

> *P3*: If you're watching something, you don't want to have a video up of someone else most of the time.

> *P8*: Using the wee video thing was good, it was better than Facetime where you can't do anything else.
> *P7*: The voice thing was good as well because you could quickly go into a message, as opposed to phoning.
> *P7*: The three options [overlayed Text/Audio/Video], I think that's a really good idea, I like that. Having it overlayed is helpful obviously.
> *P8*: It's so much quicker than the way Facetime and everything is, phoning. And also I could just say something instead of waiting for you to answer the phone, I could just say what I wanted to say.

> *P9*: When you're watching a TV program you've already got a visual element and a vocal element, so the text was perfect.

CONTENT SYNCHRONIZATION (RQ 4.4) Regarding media synchronization, there were no negative comments. Indeed, couples appeared to be satisfied with the perceived synchronization and the level of control over re-synchronization:

> *P2*: The sync was actually quite good, because [my partner] was behind me and I was saying "this is coming up", and then I re-synced it and we were quite good.

> *P5*: Sometimes we'd be watching something for about an hour, and it was like 9 seconds out roughly, but we didn't really bother [re-synchronizing] because it was close enough that you were watching something. Whereas if you were watching something normally, and one person pauses it for a break then you'd be 10 minutes out! It was good we could both pause it.

P7: Almost knowing it was synchronous is better.
P8: And pausing it when we walk away, like sometimes I pause stuff and leave the room and then he's in front of me and I'm behind, it was better that we were together.

P9: The little things [made it easier], like making sure it's synced by just pressing the button, even though the other persons actually watching it.

EFFECTS OF USAGE (RQ 4.2) Fundamentally, couples agreed that the system made them feel closer and more connected to their partners, and that the system was not a burden or perceived as being intrusive during the week long deployments:

P3: I would say so, slightly more connected, just in terms of the fact that one of the things you don't get to do if you're living apart is watch things simultaneously, it takes a lot more effort to do that anyway, you need to like, whereas with this you press a button and that's it.
P4: Yes – I think it made us feel closer and more connected because we would arrange to watch something then could discuss it. Made it more fun and intriguing watching something knowing he was too and we could then discuss during or after.

P6: It helped.
P5: It was good, it was nice, the idea that you'd make time for each other, we'd watch a lot of the same stuff anyway, it was nice to actually sit down and watch it together and talk about it as you were watching it.
P6: We have a lot of communication anyway, so it's not like it added more communication to our relationship, it was more the point that we were actually doing it, watching something, together.

P7: Help I'd say.
P8: Yeah, it was good to watch stuff together.

P9: It helped.
P10: I'd agree.
P9: Definitely didn't hinder. It was just like a different way to talk to each other really. And do something we would have done if we were together, but we didn't have to be together.
P10: Or do something that we would have done separately, but be able to share it.
I: Did the system make you feel closer or more connected?
P9: Closer.
P10: I'd say so, I guess just by sharing an experience.
P9: It's something you could have done anyway if you synced it up beforehand.
P10: But it makes it a lot easier.
P9: A lot easier. The fact that the little things, like making sure it's synced by just pressing the button, even though the other persons actually watching it.

6.2.3 DISCUSSION OF EXPERIMENT 6

The results of this study firstly emphasize that synchronous at-a-distance TV consumption can play a significant role a relationship at-a-distance. Perceived togetherness, frequency and quality of communications, and qualitative feedback all strongly indicate the merits of smart TVs incorporating the ability to enable at-a-distance experiences (RQ 4.2). Whilst this stands to reason, given the multitude of research extolling the benefits of synchronous at-a-distance TV consumption, it is important to note that this chapter demonstrates that enabling these experiences is entirely possible within an existing consumer smart TV platform.

Secondly, these results also indicate that there is significant value in enabling the consumption of other media types synchronously at-a-distance. The examination of Music found that, where tastes in Music are aligned, it can offer a shared backdrop to users which is, in many cases, just as effective as TV content, allowing couples to feel closer to each other whilst engaging in other activities. With respect to RQ 4.1, the results show that whilst TV viewing dominated usage of the system, for one couple Music was the preferred means of interacting at-a-distance, whilst all couples engaged in both TV and Music consumption to a significant degree, and two couples actively expressing an interest in continuing to use the system for at-a-distance Music consumption. However, it is important to note that unlike TV consumption, which was universally praised, Music was dichotomous. For three couples, Music either did not interest them or was an inappropriate form of media to be consumed at-a-distance. TV remained the most universally acceptable form of media.

Thirdly, whilst prior literature has emphasized that VMC was the preferred and primary means of communication at-a-distance, reinforcing closeness and presence in the process, for four of our five couples Text chat was significantly preferred (RQ 4.3). This begins to raise a question regarding the statement by [133] that "the communication media fidelity plays a strong role in the social connection of the experience". In his examination of voice and text chat, Geerts [61] suggested that text chat would be preferred by "younger users and users having more experience with chatting on computers", and these results appear to extend this finding to general VMC usage, given the low average age of the couples in this study. There is a caveat to this however: VMC was examined only with respect to how best to practically enable this within the constraint of existing consumer technology. VMC where the video is captured from an alternate viewpoint in the room, and rendered on the TV itself, might well exhibit significantly different results with respect to user preference. However, in this study, VMC was used sparingly, with users typically employing this high-bandwidth modality at the start or end of CastAway sessions.

During the sessions, couples instead relied on Text communications. They did so for a variety of reasons. Firstly, Text is low-engagement and likely better suited to media multitasking (as suggested by the participant's frequent opening / closing of the text entry dialog), allowing couples to attend to the TV content with relatively little audio / visual interruption. Secondly, there are still social acceptability issues around VMC use. Interestingly, for one couple this implementation of VMC (whereby users could select any permutation of Text / Audio / Video to communicate on dynamically, without necessitating reciprocal communications from their partner) alleviated their concerns regarding using VMC, by allowing frequent transitions between communications modalities without the more heavyweight instantiation of an explicit video chat.

Finally, this reliance on Text likely had implications for RQ 4.4, regarding the extent to which users perceived the need to re-synchronize their streams. As demonstrated in the results section, there were a number of occasions across the groups where Chromecast playback de-synchronized significantly (e.g. multiple caching events, internet connectivity problems). However, the number of re-synchronization attempts was low, and often significant delays were tolerated by users, with seemingly little effect on perceived synchronization for the system as a whole. If the couples had relied upon VMC, and had immediate, low-latency communications with their partners (and the crosstalk of hearing their partners TV playback in the background) there is a possibility that there would have been significantly more re-synchronization attempts, in line with [62]. However, because the couples relied on Text communication, delays in content playback were likely made less perceptible, or, at the very least, not important enough to merit an attempt to re-sync.

Fundamentally, this suggests there is a low barrier for entry to facilitating synchronous TV experiences, with Text chat sufficient for communication, and re-synchronization perhaps only becoming necessary when delays exceed 10 seconds, with this constraint likely increasing / decreasing based on the timeliness of the content (e.g. live sports), the engagement of the users (e.g. becoming less necessary when the TV fulfils the function of shared background noise) and the communications modality employed. In such cases, avoiding unnecessary re-synchronization may be more beneficial to users than aggressively maintaining synchronization, however further research would be required in order to establish this.

6.3 CONCLUSIONS AND RESEARCH QUESTION 4

Research Question 4 asked:

> How can TVs support synchronous at-a-distance use with a partner?

The creation and evaluation of CastAway answers RQ 4 by demonstrating the suitability of adapting an existing smart TV platform to support synchronous at-a-distance experiences, in an ecologically valid way, enabling these experiences with existing Chromecast applications. This was achieved by intercepting Chromecast APIs, re-routing calls via the cloud, and then executing these calls in order on geographically separated clients. In five weeks of in-the-wild deployments of CastAway across five at-a-distance couples, participants found significant benefit from having use of this system, with this usage leading to increased frequency, duration, and quality of communication, bringing couples closer together in the process.

Moreover, new behaviours have been elicited regarding how couples communicate when consuming TV and Music together synchronously at-a-distance, and it has also been determined that the synchronization guidelines outlined by previous research could be relaxed, depending on how couples are communicating and what content they are consuming. More broadly, this research suggests that the benefits of at-a-distance media consumption are not confined to viewing TV together; other experiences may have similar merits, with Music serving as an example of this. This work suggests that the scope of investigations into at-a-distance media consumption should be broadened beyond traditional TV programs and films.

Commercial implementation of CastAway would undoubtedly face significant challenges, for example in ensuring all in a Chromecast session have adequate rights for the media being consumed, and designing for scalability across more than two people or more than two households (e.g. in terms of how VMC is facilitated [231]). However, such issues are surmountable. A system such as CastAway offers a low barrier of entry for consumers and smart TV platforms, given the ubiquity of smartphones, the popularity and low cost of Google Chromecast and the availability of Chromecast support in Android TV, a smart TV Operating System adopted by a number of TV manufacturers (Sony, Sharp and Phillips). Given the existing prevalence of co-viewing at-a-distance, and the positive and very human impact such a feature could have on relationships, CastAway makes a strong case for smart TVs to support at-a-distance social experiences in the near future.

Fundamentally, this research has elicited insights into how consumers might engage in at-a-distance experiences in the near future using TV technology. Synchronous at-a-distance experiences can be facilitated on consumer TV platforms, bestowing the benefits of these experiences to any couple that each have a TV, an internet connection, and a $35 dollar smart TV dongle.

Given the results from Experiment 6, the answer to Research Question 4 is that the Google Chromecast TV platform can support synchronous at-a-distance use with a partner, and that there are few impediments to bringing synchronous at-a-distance experiences to those geographically separated from their partner, friends or family. This thesis affirms that given this finding, TV platforms should re-evaluate their lack of support for synchronous at-a-distance usage.

7. USABILITY OF VR HMDS

THE TV has been the dominant means by which immersive media has been consumed in the home for decades. Enhancements to the TV have led to displays that can provide cinematic viewing experiences in terms of size, clarity and resolution, the rendering of stereoscopic content to all those in the room, and even curved displays to accommodate viewing from multiple angles. These enhancements are, at least in part, intended to increase the immersion experienced by viewers, providing depth and clarity. Whilst these enhancements increase the value of the TV from the point of view of immersion, there is however another class of display which is belatedly re-entering the consumer domain, one whose capability for immersion far exceeds even the best TVs currently available.

Virtual Reality Head-Mounted Displays (VR HMDs) such as the Oculus Rift are seeing a resurgence as a means for entertainment. New consumer head-mounted displays take advantage of low weight, low cost, high resolution displays, delivering rich and immersive VR experiences. They do so by occluding the user's view of reality, instead presenting a wide field of view stereoscopic window into a virtual world. Combined with head tracking, this allows the user to freely view the virtual world in 360°. Through this, place and plausibility

The contents of Chapter 7 come from a paper written in collaboration with Daniel Boland (joint first author with myself). The joint contribution was the conceptualization of Engagement-Dependent Augmented Virtuality. In his thesis [20], Daniel discusses a typing study examining the impact that selectively blending reality based on user engagement has on typing performance, demonstrating the viability and necessity of Engagement-Dependent Augmented Virtuality for interaction. The joint contribution was in a study examining how much reality should be blended, and when it should be blended which led to the formulation of Engagement-Dependent Augmented Virtuality [136]. This thesis presents two aspects of this work that were contributed by myself: firstly, a survey investigating usability impediments in VR. Secondly, an experiment examining the application of Engagement-Dependent Augmented Virtuality to the awareness of others in a shared space. My discussion of the joint contribution is also included in this chapter to bridge the gap between the survey and the application of Engagement-Dependent Augmented Virtuality to the social presence of others in a shared space.

illusion [197] (hereafter referred to by the more general term of “presence”) is established in a virtual world, to varying extents based on numerous factors such as the fidelity of the HMD, the field of view of the headset, the quality of the rendering, the means by which interaction occurs with virtuality and so on.

This occlusion of reality is both VR’s greatest strength and also its most significant weakness; when wearing a HMD, one’s visual (and often auditory) connection to the “outside” world is diminished, promoting strong feelings of presence in the virtual environment. However, even tasks as simple as picking up a cup become difficult without visual reference, whilst awareness of who else is even in the room is likely denied to the VR HMD user.

Research Question 5 asks:

> Should VR HMDs provide the ability to be aware of, and engage with, others in the same room, and how?

This Chapter firstly describes a survey (Section 7.1) into the significance and prevalence of usability impediments such as being unable to see interactive objects or proximate persons. Section 7.2 then provides an overview of a generalized solution to some of these impediments created in collaboration with Daniel Boland, in the form of Engagement-Dependent Augmented Virtuality, where reality can be selectively incorporated as and when necessary based on inferred user engagement with that reality. Section 7.3 then presents a study examining how the concept of Engagement-Dependent Augmented Virtuality can be applied to the social presence of others in the same room.

7.1 SURVEY: USABILITY IMPEDIMENTS IN VR HMD

A survey was developed to elicit general usability concerns, to examine how users interact with peripherals and objects, and find impediments to VR HMD use. A second, more focused, stage of the survey investigated the extent to which interaction with, and awareness of, reality posed significant concerns for the usability of VR HMDs. The survey was sent to mailing lists (covering University staff, students and HCI practitioners), as well as online forums and VR-related communities, receiving 108 responses in total. Questions were not forced choice. The survey was conducted from August to September of 2014. See Appendix J for the full questionnaire.

7.1.0.1 EXISTING USAGE

The most used headsets were the Oculus Rift DK1 (used by 49% of respondents) and DK2 (79%), with others such as Google Cardboard having been used by under 5% of respondents.

75% of respondents used VR HMDs weekly or more frequently, with 36% using them daily. 97% of respondents had used the headsets for gaming, 60% for media (e.g. films, TV), 52% for simulation, 14% for productivity, 10% for therapeutic uses and 10% for modelling and game development. In terms of auditory feedback, headphones were used by the majority of respondents (82%: In-Ear (13%), Enclosed (57%), Noise Cancelling (10%), and Bone-conduction (1%)), with a minority (17%) using speakers. Of interest is the fact that 80% of users actively try to cancel out any perception of real-world audio.

7.1.0.2 IMPEDIMENTS TO VR USAGE AND ENJOYMENT

Participants were asked about potential impediments to the usage and enjoyment of HMDs to ascertain the relative importance of interaction with reality versus typical complaints regarding VR HMDs (e.g. in terms of nausea, poor resolution, etc.). As can be seen in Figure 7.1, while the technical capabilities of HMDs dominated, interaction with peripherals and real world objects were rated highly, with over half of respondents agreeing or strongly agreeing that these were currently impediments to their HMD usage.

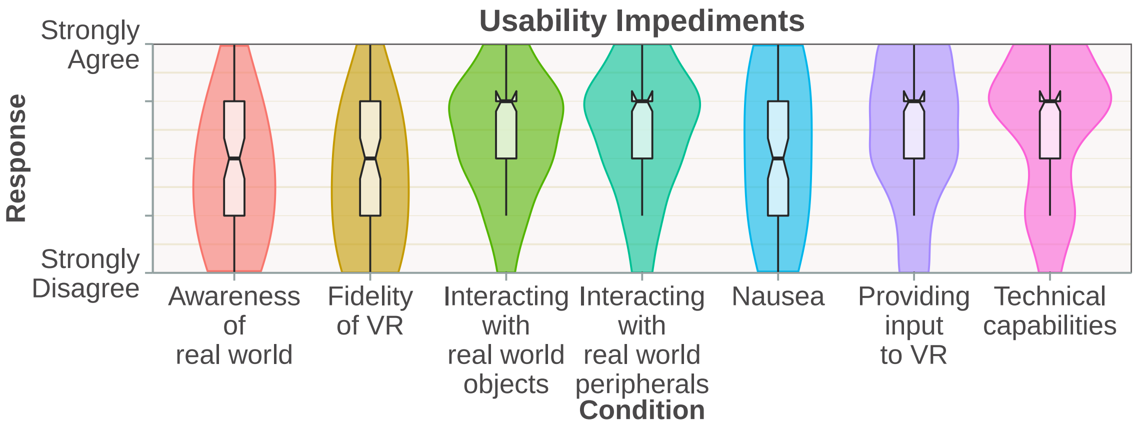


Figure 7.1: “To what extent do you agree that the following IMPEDE your ability to use and enjoy VR HMDs?”. Aspects ordered by mean score highest to lowest, areas questioned were: *Technical capabilities of headset* (e.g. head tracking, resolution, latency); *Nausea when using headset*; *Fidelity of virtual world* (e.g. how real does it look); *Awareness of real world* (e.g. who is there); *Interacting with real world objects* (e.g. picking up a cup); *Interacting with real world peripherals* (e.g. via keyboard, mouse, motion controllers..); *Providing input to the virtual world* (e.g. via peripherals, gesture, voice etc.); n=81.

7.1.0.3 INTERACTING WITH REALITY

To interact accurately with the real world, users currently need to remove the HMD. The survey sought to establish how often they interrupt their VR experience to do so, and how frustrating they found this. While this is not a particularly frequent occurrence, it is frustrating for users to have to resort to this behaviour. Figure 7.2 shows the distribution of responses for frequency with respect to taking the headset off versus frustration.

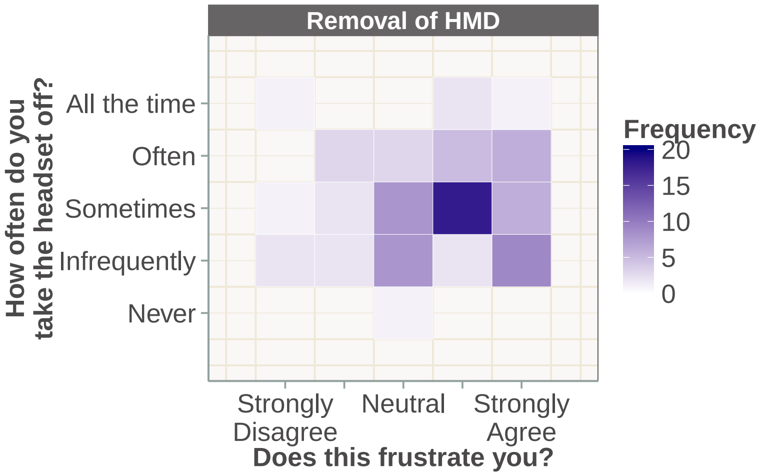


Figure 7.2: Responses to "When using the VR HMD, how often do you take the headset off (lifting it off your eyes temporarily, removing it etc.) in order to interact with, or gain awareness of, the real world?" and "Having to remove the VR HMD in order to interact with reality frustrates me". Colour indicates frequency, darker is more frequent. n=81.

Participants were then asked to gauge how effectively they currently manage to interact with three aspects of reality: objects, others (proximate persons) and peripherals, as well as to what extent they agreed that VR HMDs should better facilitate interaction with these, as seen in Figure 7.3.

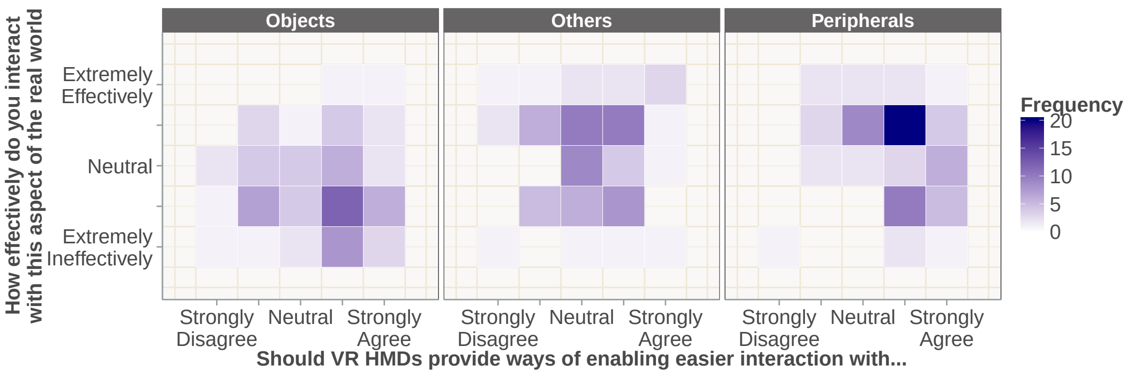


Figure 7.3: Responses to "How effectively do you interact with the real world when wearing a VR HMD in the following contexts" and "Do you agree that VR HMDs should provide ways of enabling easier interaction (e.g. seeing / hearing) with the following". n=76.

Interaction with 'objects' is mostly rated extremely ineffective, with strong agreement that such capability should be better facilitated. Interacting with peripherals is somewhat dichotomous in terms of effectiveness, with users congregating around either effectiveness or ineffectiveness with respect to their capacity to interact with others. However, the majority wish for this capability to be facilitated, bringing into question how well users can accurately gauge their capability to interact with commonly used peripherals. With respect to interacting with others, the majority considered themselves able to interact with others effectively and were neutral tending toward agree with respect to whether this should be better facilitated. This is likely strongly tied to the usage contexts: the majority of respondents polled who used VR headsets, used them in private spaces / predominantly alone (80%).

7.1.0.4 AWARENESS OF ENVIRONMENT AND OTHERS

Figure 7.4 looks at which aspects of awareness of others and the environment were most problematic for HMD users. Of particular note were awareness of *Others* and their *Proximity* which were both rated poorly in terms of existing awareness, and strongly in terms of whether VR HMDs should support these aspects of awareness. Interestingly, interaction with others was distributed between unaware and aware, yet the majority of respondents agreed that this aspect of reality could be improved. *Context* was predominantly neutral on both counts, whilst explicitly *Hearing* what is happening showed a high degree of dispersal; this is presumably because of the different volume levels regarding VR and headphone types employed.

The impact lack of awareness might have on comfort and anxiety was also considered. When asked if they agreed with the statement "I experience anxiety regarding my inability to tell what is happening around me", only 22% of respondents agreed. When asked if they agreed with the statement "My level of awareness is enough that I feel comfortable and secure in my personal surroundings" only 12% disagreed. Where users lack awareness of what is going on around them, this does not appear to lead to undue anxiety or discomfort at the current time.

7.1.0.5 SURVEY DISCUSSION

The survey identified users' desire for easier interaction with objects and peripherals. The (in)ability to provide input into VR was rated as a greater impediment to VR usage and enjoyment than nausea. It was also found that, while awareness of the real world in general is not presently an impediment to usage, there are aspects of awareness that should be prioritised – the social presence of others and their proximity. With respect to RQ 5, these results suggested the importance of VR HMDs providing the means to be aware of who else is in the room, and how close they are to the VR HMD user.

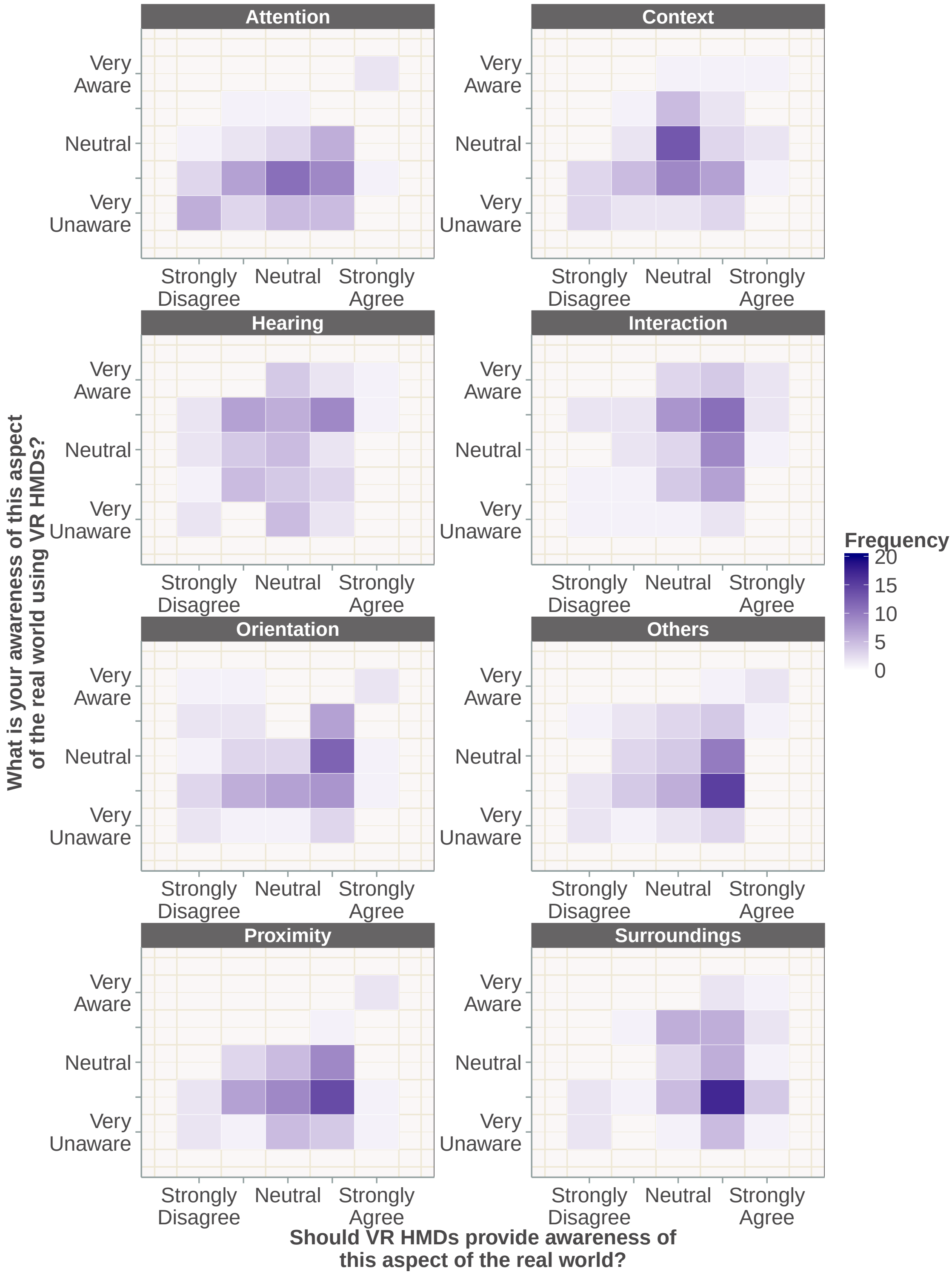


Figure 7.4: Aspects of awareness surveyed: *Attention* (e.g. knowing if you are being observed); *Context* (e.g. knowing what is happening around you); *Hearing* what is happening (e.g. movement, talking) *Interaction* (e.g. knowing someone is trying to talk to you); *Orientation* (e.g. knowing spatially where you are and where you are facing); *Others* (e.g. knowing others have entered the room); *Proximity* (e.g. knowing how close others are); *Surroundings* (e.g. knowing you are close to a wall). n=68.

7.2 DISCUSSION: ENGAGEMENT-DEPENDENT AUGMENTED VIRTUALITY

More generally, the survey results emphasized that incorporating reality into virtuality, be it proximate persons, or interactive objects, was a necessity for future VR HMD users. Based on the findings of this survey, McGill *et al.* [136] developed guidelines regarding how reality should be blended with virtuality, and when. Their approach was termed "Engagement Dependent Augmented Virtuality" (ED AV). They demonstrated the effect that incorporating elements of reality into virtuality had on a users sense of presence in VR. They found that in incorporating reality, the users sense of presence in VR was negatively affected, and that this effect varied with the amount of reality incorporated. Thus, the first guideline of ED AV was that the minimal amount of reality necessary for a given interaction should be incorporated into the VR scene, as can be seen in Figure 7.6.

Secondly, they found that incorporating reality based on inferred engagement (e.g. the user putting down the game controller and reaching out) was superior to giving the user direct control of engagement (e.g. pressing a button to reveal reality). Inferring the presence of reality was preferred by users (see Figure 7.5) and improved spatial presence and users sense of being there.

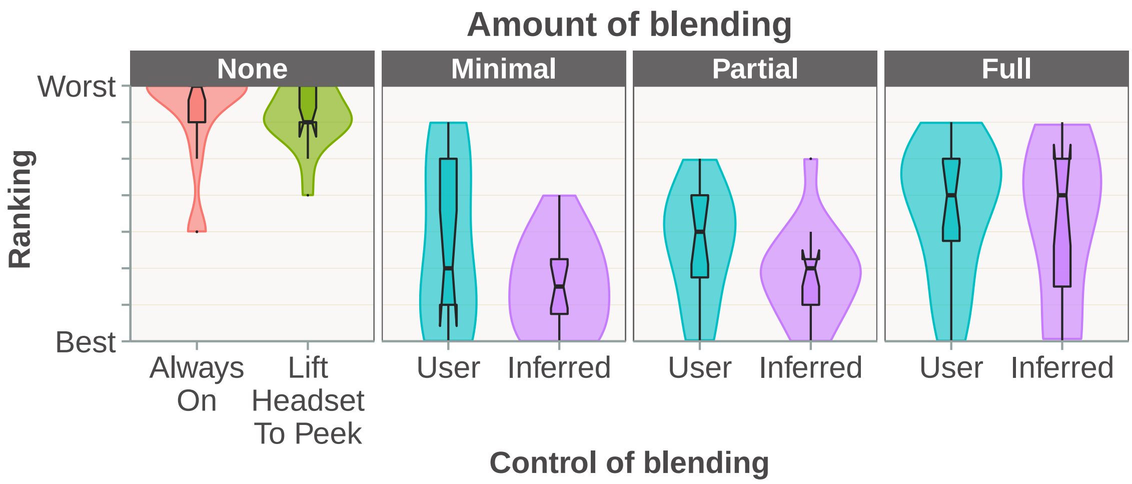


Figure 7.5: User ranking of preference (lower is better) plot of quartiles (25th, 50th, 75th) for **Control** and **Blending** factors, with comparative baselines of no blending included.

They concluded that ED AV could represent a generalised solution to incorporating reality into virtuality whilst minimizing the impact had on a user's sense of presence in VR. With respect to RQ 5, this is relevant because this guideline was used as the basis for how others in the same room as a VR HMD user could be brought into view.

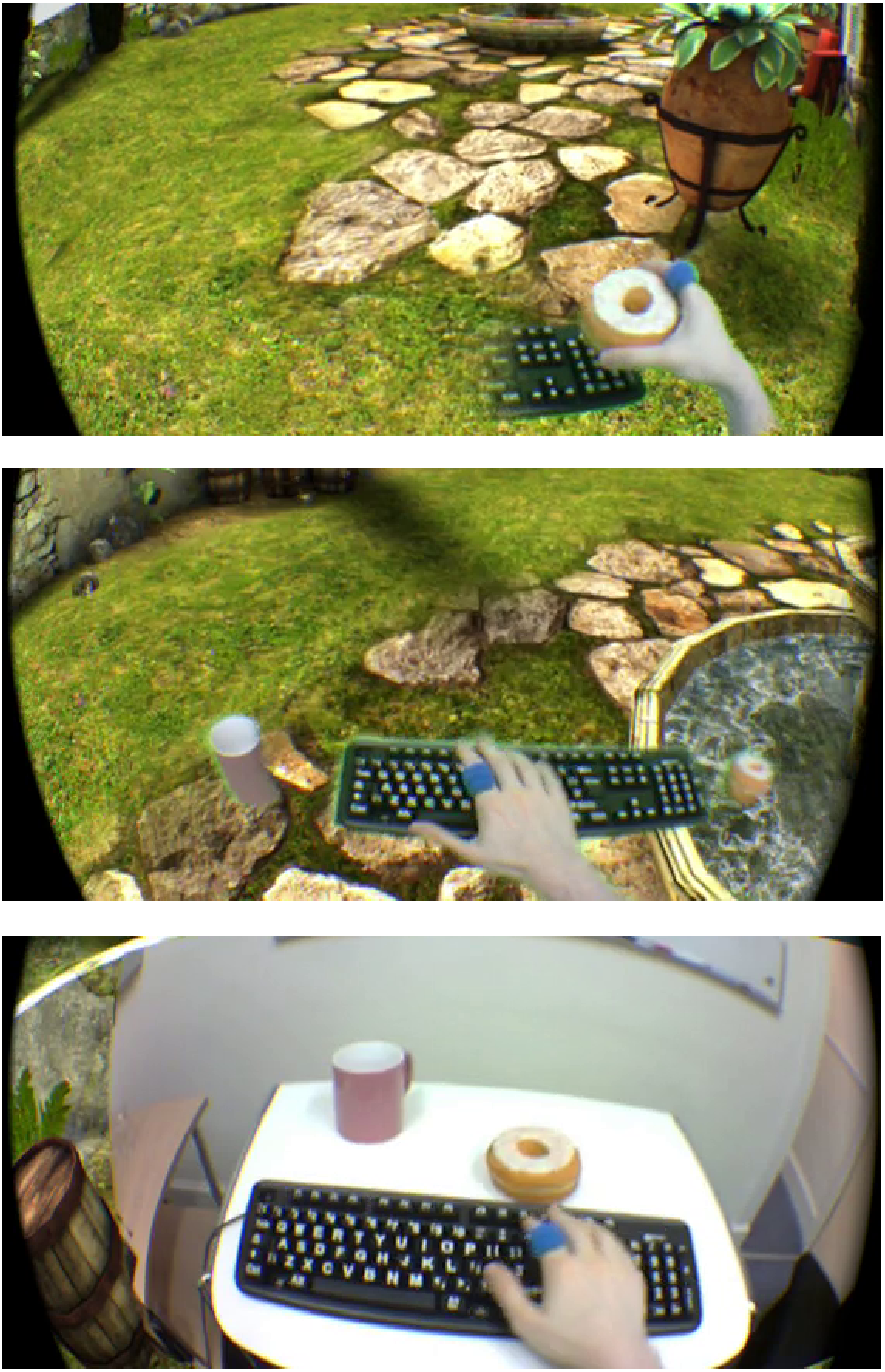


Figure 7.6: Top: *Minimal blending* (reality around user's hands). Middle: *Partial blending* (all interactive objects). Bottom: *Full blending* (all of reality)

7.3 EXPERIMENT 7: EXISTENCE OF OTHERS

From the results of the survey and the work by McGill *et al.* regarding Engagement-Dependent Augmented Virtuality, the question was then: can engagement-dependence be applied to the most important aspects of awareness from the survey, namely the existence and proximity of others. This would in turn answer the latter part of RQ 5, namely how others in the same room should be brought into VR. However, within this context, engagement is significantly more problematic to define. Whereas previously, the user implicitly knew of the existence of objects to engage with, in this case s/he may not know that there is anyone nearby in reality to engage with. Equally, those in reality can choose to engage with the HMD user, likely governed by a variety of social cues, however the user might well remain oblivious to this.

The concept of engagement here is no longer binary: there is both a necessity for a low (or casual) engagement state for a base awareness that there is potentially someone to engage with, and an accommodation for intermediary states between casual and full engagement e.g. being aware of someone, then introducing more detail as the user engages (who is there, what are they doing, etc.). Given this, this Experiment investigated not how engagement is defined, measured and inferred in this context, but how the reality of proximate persons might be communicated in both a low engagement state and a fully engaged state, again with an emphasis on how to minimise the impact this view of reality had on the VR experience.

7.3.1 IMPLEMENTATION AND DESIGN

The existence and proximity of nearby persons in reality was to be communicated by inserting user silhouettes captured by a Microsoft Kinect into the VR scene in realtime. These cut-outs were acquired using Kinect tracking and depth maps of proximate persons, and were positioned in VR at the same distance and position from the user as in reality. The direct mapping between reality and virtuality was maintained, regardless of the user's position in virtuality. The Kinect was physically positioned alongside the user, who was sat at the rear of the room, thus it captured the usable space of the room in front of the user. The aim was to provide users with an equivalent perception of their surroundings and personal space as they would have without wearing the HMD – a person 1 metre away in reality would be in the same place 1 metre away in VR. For the low engagement, casual awareness state, the inserted proximate person was presented as a ghost-like transparent figure. For full engagement, the relevant section of reality (the proximate person) was presented fully opaque, as with the partial blending condition in the previous study. For a video of the system in use, see [1].

[1]https://www.youtube.com/watch?v=SHdfxuh7_GY

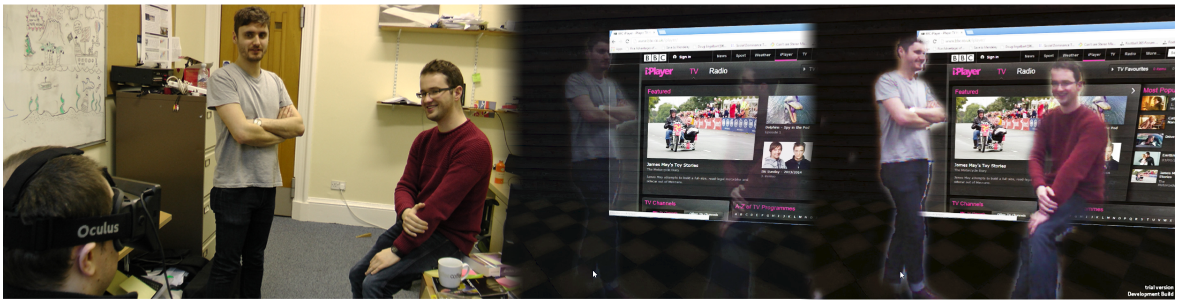


Figure 7.7: The evaluated low and high engagement states. When a person enters the same physical space as the VR user, they are faded into the virtual view. When the user wishes to engage with them, they would become fully opaque. Left: reality; Middle: Low engagement; Right: High engagement.

7.3.2 STUDY DESIGN

In this study, the aim was to establish firstly that awareness of social presence and proximity could be improved through using room-based sensors (the high engagement state), and secondly that a reduced level of awareness could be communicated, allowing for some preservation of the user's sense of presence (the low engagement state). In applying these states to ED AV, the user could persistently remain in the low engagement state, and elevate to the high engagement state when either the user wished to engage with proximate persons, or when the proximate persons wished to engage with the user.

Twelve participants were recruited from University mailing lists (Age mean=27.8, SD=4.76, 11 male 1 female). It was hypothesized that as awareness increased, the user's sense of presence would diminish as s/he would suffer increased distraction from their VR experience. The three conditions evaluated were *(1) Baseline:* The normal VR environment; *(2) Low engagement:* With a transparent, ghost-like social presence in virtuality, and *(3) Full engagement:* With an opaque social presence in virtuality.

These engagement states are depicted in Figure 7.7. For the VR scene, a modified version of the Tuscany Villa[2] was used – a scene developed by Oculus to showcase the immersive capability of VR. Users were instructed on how to navigate in the scene, then given 3 minutes per condition to explore the villa as they desired using a gamepad whilst wearing the Oculus Rift DK1 and in-ear headphones. Conditions were counterbalanced. To provide meaningful feedback of activity in reality, every 30 seconds the experimenter would enter the view of the Kinect and perform one of three activities for 15 seconds: writing on a whiteboard, standing using a phone, and sitting down. Sense of presence was again measured by the IPQ. For measuring the participants' awareness of social presence in reality, the "Social Presence – Passive Interpersonal" factor from the Temple Presence Inventory [128] was used. Awareness, comfort and distraction were measured using a 7-point Likert scale. Sense of presence

[2] share.oculusvr.com/app/oculus-tuscany-demo

was measured using the Igroup Presence Questionnaire (IPQ) [190] as it is generalised and widely used in the literature. See Appendix K for experimental materials (question set and plain language statement given to participants).

7.3.3 RESULTS

A Friedman test with *post hoc* Wilcoxon's tests was performed where applicable. Results can be seen in Table 7.1. There was no significant difference in sense of presence (the IPQ scales) as the amount of reality present varied, however mean involvement was lower, as can be seen in Figure 7.8.

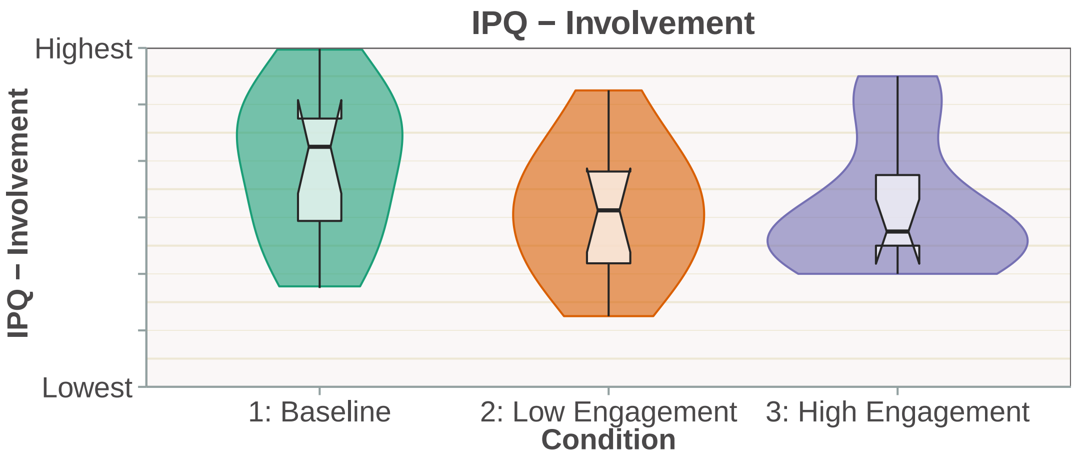


Figure 7.8: IPQ Involvement subscale. Higher is more involved.

The both the full view, and "ghost" view of proximate persons statistically increased both distraction due to, and awareness of, reality (see Figure 7.9).

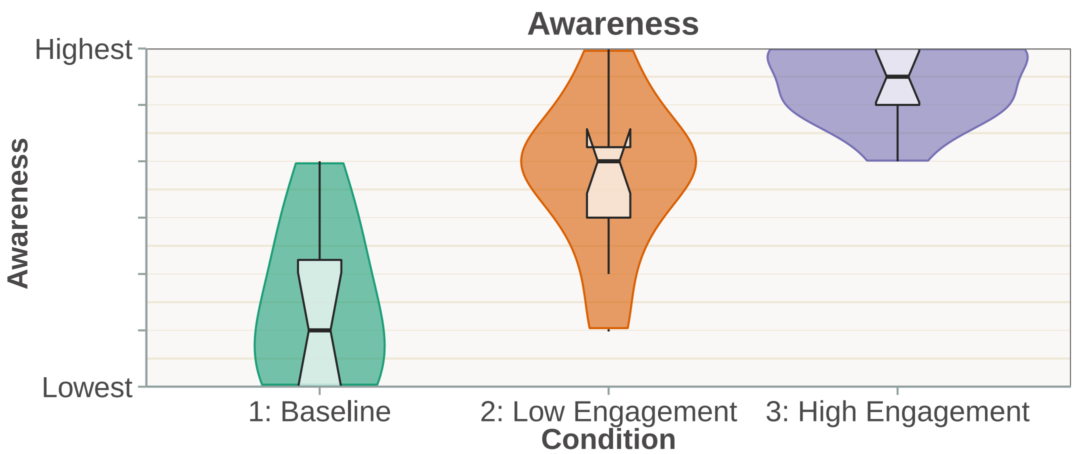


Figure 7.9: Responses to the question "How aware were you of the presence of others?"

Factor	1: Baseline	2: Low engage	3: Full engage	Friedman Test	Wilcoxon *Post-hoc*
IPQ Spatial: The sense of being physically present in the Virtual Environment	4.23 (0.90)	4.48 (0.72)	4.40 (0.74)	$p = 0.50$	NA
IPQ Involvement: Measuring the attention devoted to the Virtual Environment and the involvement experienced	3.92 (1.30)	3.12 (1.16)	3.23 (1.21)	$p = 0.09$	NA
IPQ Realism: measuring the subjective experience of realism in the Virtual Environment	3.25 (0.81)	3.46 (1.16)	3.00 (1.26)	$p = 0.14$	NA
IPQ Sense of being there: Sense of being in the Virtual Environment	4.50 (0.91)	4.42 (0.79)	4.25 (1.29)	$p = 0.87$	NA
TPI Passive Interpersonal Social Presence: Measuring the perceivability of facial expressions, style of dress, and body language	0.92 (1.12)	2.53 (1.67)	4.56 (0.91)	$\chi^2(2) = 20.7, p < 0.01$	1-3, 2-3
Distraction: "How distracting did you find reality in this virtual reality experience?"	1.17 (0.84)	2.92 (1.62)	3.08 (1.83)	$\chi^2(2) = 9.41, p < 0.01$	1-2, 1-3
Awareness: "How aware were you of the presence of others?"	1.42 (1.38)	3.75 (1.36)	5.42 (0.67)	$\chi^2(2) = 21, p < 0.01$	1-2, 1-3, 3-2
Comfort: "How comfortable did you feel with regards to your personal space?"	4.58 (1.31)	4.00 (1.65)	4.00 (1.76)	$p = 0.56$	NA

Table 7.1: Means (Std. deviation). IPQ, higher is better. TPI Social Presence (Passive Interpersonal), higher is more awareness. Distraction from VR due to reality, higher is more distracting. Awareness of reality, higher is more aware. Comfort in personal space, higher is more comfortable. Friedman test was conducted with *post hoc* Bonferroni corrected Wilcoxon tests.

The TPI Passive Social Presence questionnaire also demonstrating much higher awareness of who was there in Condition 3, versus Conditions 1 / 2. Condition 2 featured more awareness than Condition 1, thus suggesting that the “Ghost” presentation did provide a more cursory awareness of social presence and proximity, as would be appropriate for a low-engagement state.

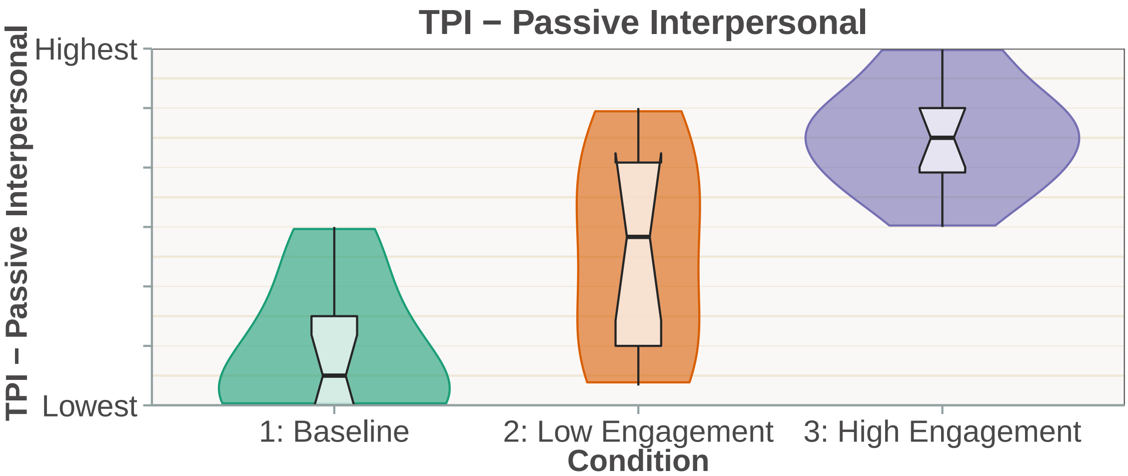


Figure 7.10: TPI Passive Social Presence questionnaire. measuring the perceivability of facial expressions, style of dress, and body language.

However, importantly, the “ghost” presentation of Condition 2 did not lead to a statistically significant difference in Distraction compared to the opaque full-engagement of Condition 3, as can be seen in Table 7.1. Thus, whilst Condition 2 provided a lower level of awareness, it did not deliver a commensurate decrease in distraction that would make this Condition appropriate as a low-engagement state. In addition, there was no effect on comfort.

7.3.3.1 INTERVIEWS

A *post hoc* interview was held with each participant. The format was semi-structured, asking their opinions on being able to perceive reality in VR. These interviews were transcribed and coded, with the most common themes discussed in this section.

GHOSTS IN THE RIFT The low engagement “ghost” condition was disliked by seven participants (58%) for a variety of reasons e.g. fidelity of rendering, breaking immersion, or being reminiscent of ghosts:

> “I didn’t really like the ghosting one, because I couldn’t really get much.. like I could see what you were doing, but I had no idea, it could have just been anybody”

> "The ghost view wasn't really very useful, because there wasn't enough person there to kind of have the benefit of the person in the world, but there's still someone there so it wasn't completely as immersive breaking, I think either the real person or nothing would be better."
>
> "Being in a villa and having this ghost like view was... horrifying"

However, for a small subset of two participants (with three others expressing no opinion either way) the low engagement condition fulfilled its brief e.g.:

> "I liked the ghost one, because it didn't interrupt with everything else, like when it was the more opaque version you kind of occluded what I was looking at, it wasn't large enough to cause a problem."

COMMUNICATION OF SOCIAL PRESENCE Participants appreciated knowing who was in the room, but frequently argued that they wanted a warning regarding the appearance of proximate persons, or that their existence be communicated more discreetly or abstractly, with a more graduated response (e.g. alerts, notifications), with seven participants (58%) wanting social presence to be communicated differently:

> "I don't think I need to see the person; if it just popped up that person's name, like on XBox live or PS3 'this person wants to play with you'."
>
> "I think an example would be I'm sitting facing a monitor and I can't always tell when you come in... If they open the door (and) something came up on my monitor... I could go 'oh right' instead of having to wait for them to tap me on the shoulder"
>
> "I think that I'd need some cue before someone entered my view"
>
> "Other virtual things... flies or butterflies, you know, other virtual things could pop up to represent somebody."
>
> "We take it for granted in real life, you have all your senses, you kind of know if somebody is nearby, whereas in that sometimes you put the headset on and lose yourself."
>
> "I think that I'd need some cue beforehand before someone entered my view I would need some cue because now it was like a horrible bit where you see someone suddenly infront of you, so if you had a bit of something that warns you when you are about to see some real world"

CONTROL OVER REALITY Seven participants (58%) expressed a wish to have control over how much reality was brought into virtuality, often selectively and based on their engagement with it:

> "I'd want to know if people are looking at me, or if they are looking at somebody else.. so if I'm told they've entered the room I could use a slider.. gradually fade it up and see who is there, what they are doing."

> "I found the opaque view quite disruptive... If there was some way where you could just do... "boom" (go away)... but then the downside would be what if they are in the room and want to talk to you in a few minutes, how do they get your attention without hitting you?"

> "There was one or two moments where I was like go away from here!"

> "I think what I would prefer... is either to have an explicit 'where is the person' or to be able to bring it (reality) in myself, so if I was wandering about... if I get a sense of a feeling here that you wandered past me then maybe I could press a key or something. I think that the permanent, even with the opacity change, I think the permanent placement of the person in it... began to make it slightly absurd. It's not that it's breaking immersion, it's just that it's inappropriate for the immersion that you have"

> "If you were trying to do a task in it (virtuality) it might be annoying, so it'd be good to be able to just turn it on (or off)."

This preference toward reality being incorporated into virtuality on the basis of the participants engagement with reality was broadly categorised as matching the following definitions:

Binary Engagement People in reality being brought into virtuality explicitly on the HMD wearer's command

Dynamic Engagement There being gradations of feedback from reality, with users able to dynamically change their level of engagement with reality, e.g. the example given earlier of a slider to transition between the ghost-like through to opaque views as necessary.

Inferred Engagement Having the system infer when users would wish to engage with reality, e.g. proximate persons brought into virtuality when they attempted to talk, gesture, or look at the HMD user.

REALITY FITTING THE CONTEXT OF VIRTUALITY Five participants (42%) thought that the social presence of proximate persons from reality in VR scene was avatar-like or fit with virtuality (with some exceptions) e.g.:

> "With the fully opaque condition, it was.. having a real person there almost improved the.. don't know about the immersion, but it made the scene more kind of realistic and alive, because there's a real other person there, because at the moment there's fake butterflies and things and there's nobody there, it's a bit empty and nothing... Seeing a real person overlayed in the virtual world, it didn't take me out of the virtual world so much as it actually made the virtual world more realistic and engaging."

> "It also seemed plausible that you might be there, when you were in the house like you could be wandering around in that room or on the stairs. There were a couple of times you were sitting on a tree and it looked silly, but it didn't ultimately affect it (the immersion). Particularly when I was wandering outside trying to look over the balcony of the sea and suddenly you would appear floating in the air.. why are you there, that doesn't make any sense. Or like, some of the other bits where similarly you were half floating over the other side of the wall, or moving in between two barrels.. there's no reason for you to be there."

7.3.4 DISCUSSION OF EXPERIMENT 7

Incorporating reality significantly improved awareness of proximate persons, at the expense of increased distraction, with the full engagement state providing significantly improved awareness (see Table 7.1) while allowing users to remain present in VR. However, the low engagement state, while providing decreased awareness, failed to be significantly less distracting than the full engagement state. Thus it did not meet the criteria of the required low engagement state, which would be expected to facilitate some subset of awareness, with significantly less distraction that full engagement. Participant interviews suggested that the lesser, or more casual, state of awareness should likely incorporate non-visual representations of proximity and existence, not necessarily tied to gaze. A frequently mentioned concept was the use of textual alerts in messaging and gaming, where users are informed of the online presence of contacts. This approach was cited as being unobtrusive, while conveying the most important information: who is there and what they are doing.

Interestingly, in varying the amount of reality when rendering proximate persons, markedly different effects were seen compared to interactive objects and peripherals, with no significant effects in terms of any of the IPQ sense of presence factors. Qualitative feedback suggests that whereas the existence of objects might be disconcerting or unnatural, the existence of people in a Tuscan villa was not problematic and was, in fact, in line with user expectations. This reflects Slater's conception of presence as *plausibility illusion* – if the view of reality is logically consistent with the context of the VR scene, this may preserve (or even reinforce) the sense of presence. While enabling engagement-dependent awareness will require future work, primarily in designing a system that can infer the engagement between the user and others, these results show how such a system might provide awareness based on engagement.

7.4 CONCLUSIONS AND RESEARCH QUESTION 5

Research Question 5 asked:

> Should VR HMDs provide the ability to be aware of, and engage with, others in the same room, and how?

In a survey of existing VR HMD users (Section 7.1) it was found that an awareness of proximity and social presence was strongly desired by existing VR HMD users. Section 7.3 then examined how this awareness could be provided, governed by engagement (Engagement Dependent Augmented virtuality). By incorporating proximate persons into VR as silhouettes, positioned spatially in virtuality where they were relative to the VR user in reality, VR users became significantly more aware of who shared their physical space. However, ED AV suggests that this representation should be used only when the user and proximate person(s) are attending to each other in some fashion. Thus this study also attempted to elicit a means by which a low engagement state could be provided, where the VR user received less information about who was in the room, and where they were, to preserve immersion. The trialled low engagement state (translucent silhouettes) succeeded in terms of providing a lesser, casual awareness of proximity and social presence, but failed to be less distracting that the full engagement state. User interviews did however suggest a number of ways by which social presence and proximity could be communicated in low engagement ways e.g. augmenting the virtual environment.

Future research will be required to establish suitable low engagement states for communicating social presence and proximity, for example through abstract visuals (e.g. more butterflies, notifications) or non-visual modalities (e.g. vibro-tactile feedback, audio etc.). If the user is unaware that someone has entered the room then they cannot know to increase their engagement with reality. Allowing elements of reality to initiate an engaged state with the user is a sensible approach and comparable to notifications in other interaction scenarios. In this way, users could be provided with sufficient awareness to be able to know who is in the same space, such that they could choose to engage with them if they so wished, whilst proximate persons could also initiate interactions with VR users. Moreover, future research will also be required to examine how engagement can be defined and measured in such scenarios.

Given the results from the VR usability impediments survey and Experiment 7, the answer to Research Question 5 is that VR HMDs should provide a capability for the wearer to be *aware of, and engage with, others in the same room in reality. Using room-wide sensing to render those in reality in VR, in the same virtual position as in reality relative to the VR HMD wearer, communicates both who is there, and where they are relative to the VR HMD wearer. However, this thesis affirms that, based on the definition of Engagement-Dependent Augmented Virtuality, lower-engagement states for communicating social presence are required.*

8. At-A-Distance Media Consumption Using VR HMDs

As demonstrated in Chapter 7, by assuming the presence of room-wide sensing (e.g. depth cameras such as the Kinect V2 mounted in a space such that they have a view of the majority of the room) and head-mounted sensing (e.g. wide angle cameras such as the Leap motion attached to the front of a VR HMD) mixed reality experiences using VR HMDs become feasible. In the aforementioned Chapter, head-mounted sensing was used to incorporate the user's hands, alongside interactive nearby objects, while room-wide sensing was used to capture and incorporate others in the same physical space / room. Such approaches can equally apply at-a-distance however. For example, prior telepresence research has seen users at different remote locations captured via cameras, with this captured imagery transmitted over a network and rendered in-place in a mixed reality rendering [18, 171]. This effectively allows users at-a-distance to share virtual spaces, without relying on virtual avatars [72] or telerobotics[1]. Instead, their presence can be communicated as in reality, complete with position, gestures, facial expressions, and clothing. In this way, headsets capable of mixed reality renderings, such as VR (e.g. Oculus Rift) and AR HMDs (e.g. Microsoft Hololens) can play a significant role in changing the nature of how people communicate at-a-distance. Instead of video-mediated communication viewed on a monitor or phone, the remote person being contacted can be viewed as if sharing the same physical or virtual space as others in the conversation.

In accepting this possibility, there are implications regarding synchronous at-a-distance media consumption. Instead of watching a living room TV, or going to the local Cinema, soon the viewer will be able to put on an HMD and find themselves in experiences such as their

[1] http://www.engadget.com/2015/10/26/oculus-rift-teddy-bear-adawarp/

own personal at-a-distance Cinema, or a 360° video of their favourite film [48]. Fundamentally, mixed reality VR HMD experiences have the potential to supplement, and even supplant, at-a-distance TV-based systems such as CastAway. Given this, Research Question 6 was expanded to ask:

RQ 6 How are VR HMDs likely to change the nature of synchronous media consumption at-a-distance?

- **RQ 6.1** To what extent can VR HMDs approximate the experience had when physically co-viewing together?
- **RQ 6.2** To what extent can VR HMDs exceed the experience had when co-viewing together using the TV at-a-distance?
- **RQ 6.3** Will the immersion provided by VR experiences help or hinder socialization at-a-distance?

This Chapter describes Experiment 8, examining how VR HMDs can enable shared and synchronous at-a-distance VR experiences. Shared immersive experiences are compared to physically co-viewing together, and co-viewing together at-a-distance using the TV for both viewing and communication, to answer RQ 6.1 and 6.2. Three different levels of immersion are investigated, with socialising and viewing effort examined to answer RQ 6.3.

8.1 EXPERIMENT 8

Given the importance of communication, and more specifically the fidelity of communication, in engendering intimacy at-a-distance, technologies which allow users to go beyond traditional VMC merit investigation. In striving for closeness and togetherness, VR experiences where a partner can be seen to be in the same virtual space as the user might provide the means for co-consumption at-a-distance that much more closely resembles the experiences had when physically together. In this way, VR and AR displays have the potential not only to change how people communicate, but also how they consume media together at-a-distance.

This study was intended to reflect upon the potential for shared and immersive media consumption at-a-distance, specifically using available consumer VR HMDs in the form of the Oculus Rift DK2 (SDK v0.7.0). A prototype was built that allowed for pairs of users to engage in shared VR experiences using the Unity 3D engine (v5), with the capability to see and hear each other in these experiences as if seated next to one another, by using Microsoft Kinect V2s, and audio headsets with microphones. This system allowed for the presentation of 360° photos, videos (using the Renderheads AVPro library [177] for high-performance video decoding), and fully virtual 3D content in synchronization across the users, at 75FPS. For a video of the system in use, see [2].

8.1.1 EXPERIMENTAL DESIGN

Five Conditions were defined to answer these Research Questions, as can be seen in Figure 8.1. For the baseline Condition, participants were physically seated side-by-side with shared viewing of a TV, whilst for the at-a-distance Conditions, participants were seated at opposite ends of the lab, wearing audio headsets with microphones. In the VR Conditions, participants could see their partner as if seated next to them, just outside the peripheral view when looking straight ahead in each scene, with one participant captured from the left, one from the right such that participants appeared in the correct orientation to their partners. In all Conditions, awareness of partners was kept approximately the same i.e. full body actions and gestures were capable of being observed. Participants were seated throughout. The Conditions were:

1: TV Together This was the baseline for viewing together, with participants seated next to each other viewing a 24″ TV display.

2: TV at-a-distance This was the baseline for viewing apart, based on the preference for PiP in the field study from [133], with participants being able to see each other in the bottom left/right hand corner of a 24″ TV.

3: VR TV at-a-distance Here participants found themselves in a photo sphere of the same room from Conditions 1 and 2, being able to see their partner sitting to their left/right, viewing media content on a virtual screen of similar size to that in Conditions 1 and 2.

4: VR Cinema at-a-distance Here participants were in a 3D virtual Cinema scene, with media content playing on a Cinema-sized virtual display.

5: VR 360° video at-a-distance Here participants found themselves in 360° video sphere scene.

For all Conditions bar Condition 5, the media content comprised of 8 minute clips from a nature documentary series [8]. For Condition 5, the content comprised of 360° nature documentary clips from [47]. These Conditions were chosen to quantify how much closer a person might feel to their partner when watching media content sitting next to them in a virtual space, compared to prior VMC approaches (comparing Conditions 2 and 3, answering

[2]https://youtu.be/WPkeabY-W9A

1: TV Together, with participants seated side-by-side in reality

2: TV At-A-Distance, with participants able to communicate via PiP video and headphones/microphone

3: VR TV At-A-Distance, with participants wearing VR HMDs and headphones/microphone, able to see and hear each other in VR, set in a photo sphere of the real-world lab setting

4: VR Cinema At-A-Distance, as with (3), except set in a VR cinema

5: VR 360° At-A-Distance, as with (3), except set in a 360° VR video experience

Figure 8.1: Conditions for Study 2. Condition 2 shows the view on one participant's TV screen in reality, Conditions 3 to 5 show views from the perspective of a VR partner. In all Conditions the viewing is from the perspective of the rightmost partner.

RQ 6.2) and physically sitting together (comparing Conditions 1 and 3, answering RQ 6.1). Secondly, this design allowed us to examine the effect that increasing the immersion in the media content had on participants' capability to attend to, and communicate with, their partners (answering RQ 6.3). It was intended that Condition 3 would offer the lowest immersion in the media content, owing to the dimensions of the virtual TV, and the context of the virtual setting, that of the lab space the participants were physically in, portrayed via photo sphere. The setting of Condition 4 is that which is considered most immersive for widescreen content, a Cinema. Condition 5 featured recorded 360° video, allowing the viewer to become encapsulated in the recorded world in the most immersive media content. In this way, Immersion was controlled by varying the environment and the size of the display (audio was consistent throughout).

Conditions 2-5 were counterbalanced, with Condition 1 (baseline) always recorded first to get an accurate baseline prior to VR Conditions. Each Condition lasted 8 minutes. Video clips were not randomized due to the limited amount of comparable 360°footage available for Condition 5. As such, clips were vetted for similarity in terms of content and narration. Participants were recruited from University mailing lists in pairs that knew each other (friends, family etc.), with 12 pairs (24 participants, 18 males, 6 females) recruited, with an average age of 21.6 years (SD: 4.2).

Through these conditions, shared immersive experiences were compared to physically co-viewing together, and co-viewing together at-a-distance using the TV for both viewing and communication, to answer RQs 6.1 and 6.2. Three different levels of media immersion were investigated, and socialization examined both quantitatively (through the amount of speech, and the amount of time spent looking at a partner) and qualitatively (through questionnaires) to answer RQ 6.3.

After each condition, a 36-item questionnaire was delivered to participants. This comprised of a 20-item TV / media immersion scale (from [52], used in [26], derived from questionnaires for immersion in gaming [106] and narrative engagement [30]), Social Presence and Closeness [133], emotional connection [58], synchronization [62] and engagement/togetherness [104]. Finally a questionnaire examined the preferences of participants with respect to the experiences presented for solo consumption as well as rankings of the at-a-distance Conditions, with short interviews conducted regarding preferences. Across all conditions, duration of participants speech was recorded, whilst for the VR Conditions the azimuth and polar angles of viewing were also recorded at 20 Hz, both measures of engagement. See Appendix L for experimental materials (question set and plain language statement given to participants).

8.1.2 RESULTS

8.1.2.1 QUESTIONNAIRE

For the questionnaires there was no significant effect on Social Presence ($\chi^2(4) = 6, p = 0.2$), with the VR social presence scores broadly comparable with the Control. There was, however, a significant effect on immersion ($\chi^2(4) = 58, p < 0.01$), with *post hoc* tests validating that Conditions 4 and 5 were the most immersive in terms of media content, compared to Conditions 1–3 (see Figure 8.2).

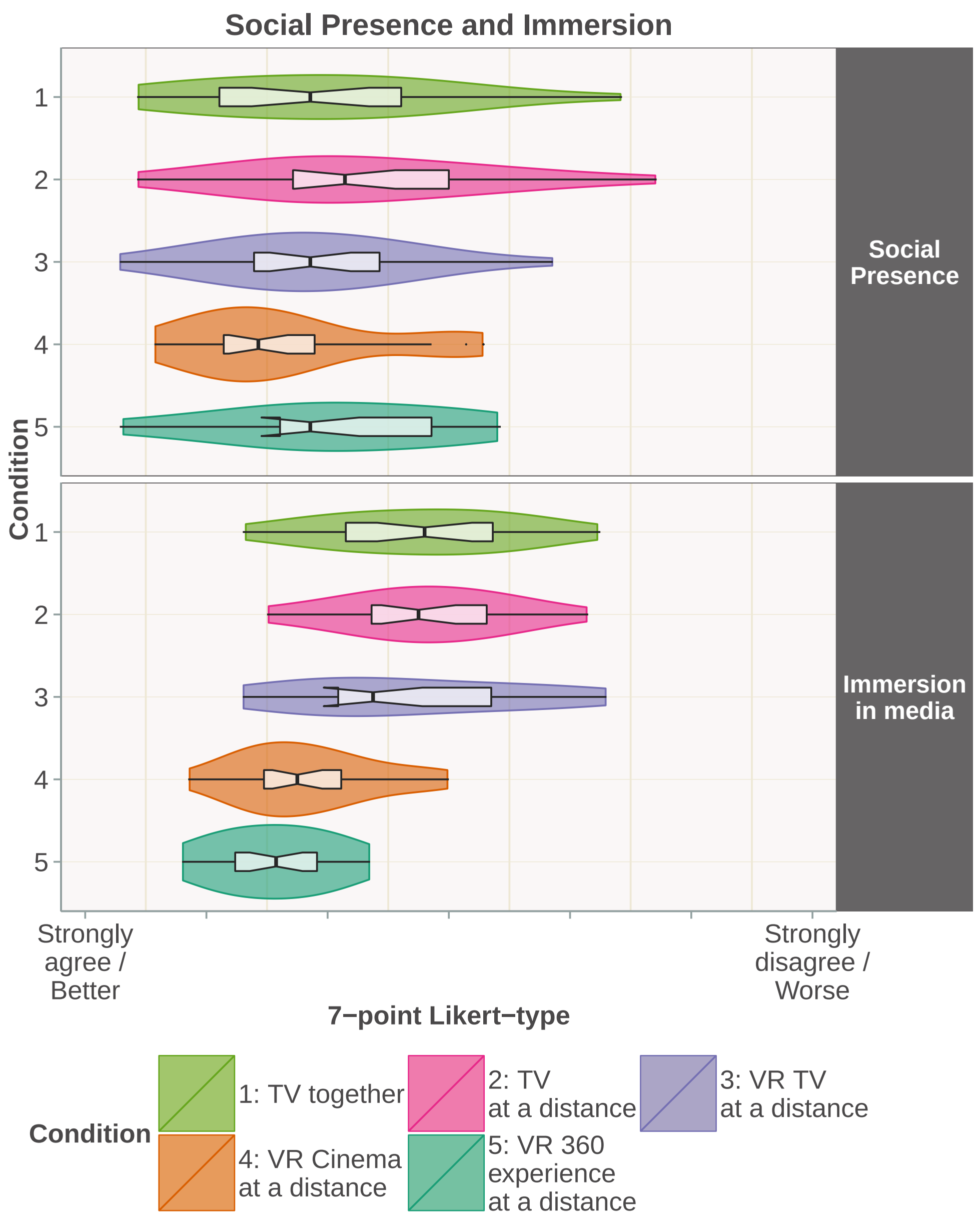


Figure 8.2: Scores from Social Presence [133] and Immersion [52] questionnaires.

The extent to which participants felt engaged ($\chi^2(4) = 46, p < 0.01$, *post hoc:* 1-4, 1-5, 2-4, 2-5, 3-4, 3-5) and enjoyed the experience ($\chi^2(4) = 38, p < 0.01$, *post hoc:* 1-5, 2-4, 2-5, 3-5, 4-5) both featured significant effects, with the more immersive VR conditions being more engaging and enjoyable. There was a significant effect on the emotional scale ($\chi^2(4) = 16, p < 0.01$), but *post hoc* tests found no significant differences (see Figure 8.3).

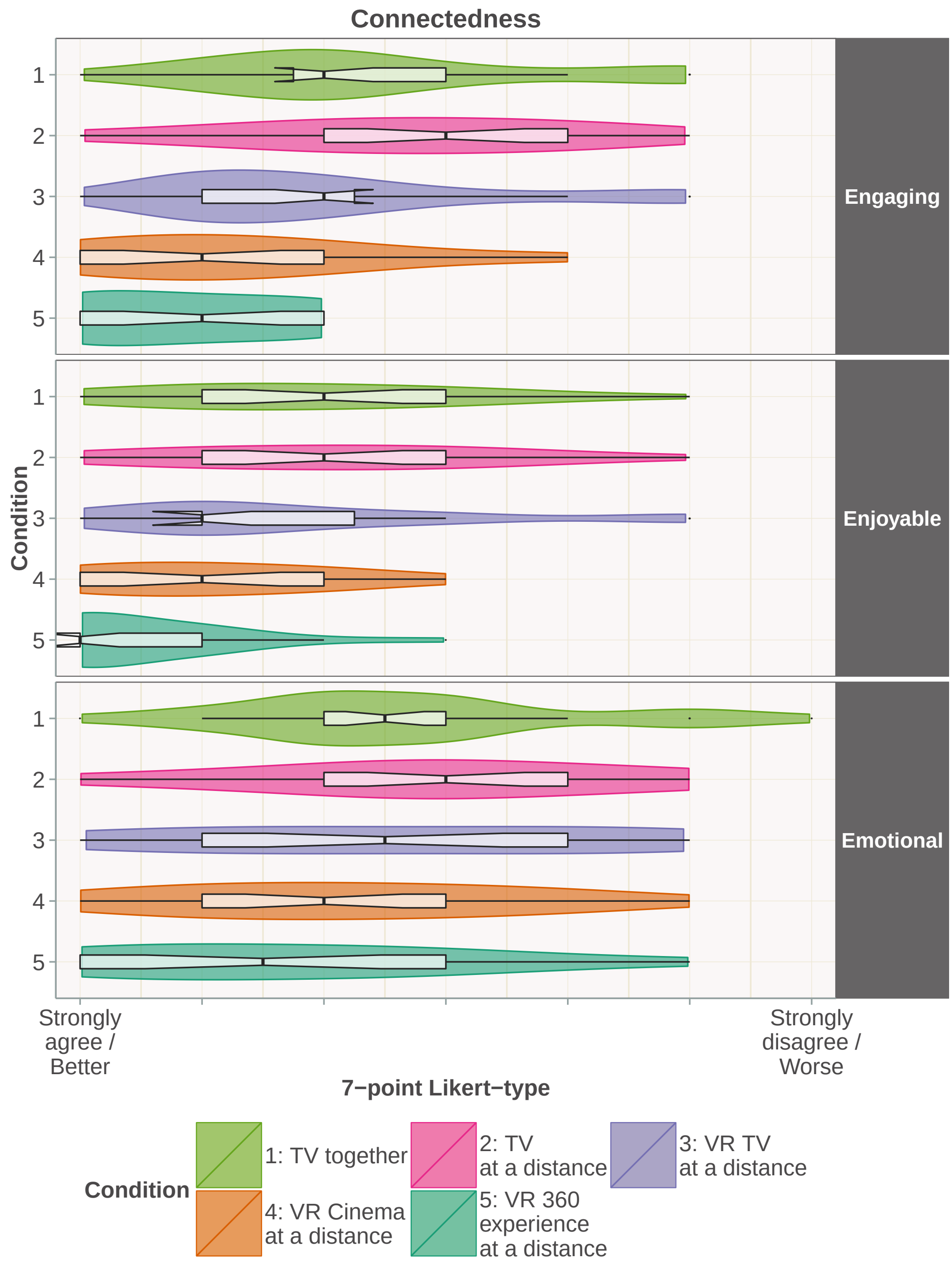


Figure 8.3: Responses for Connectedness questions [58]: "How engaging / enjoyable / emotional was it when you viewed media content with your partner?"

For synchronization there was a significant effect ($\chi^2(4) = 15, p < 0.01$) *post hoc* between Conditions 2-5. For togetherness ($\chi^2(4) = 10, p < 0.05$), there were no significant *post hoc* differences, whilst for experience ($\chi^2(4) = 16, p < 0.01$) there were significant *post hoc* differences between 2-4 and 2-5 (see Figure 8.4).

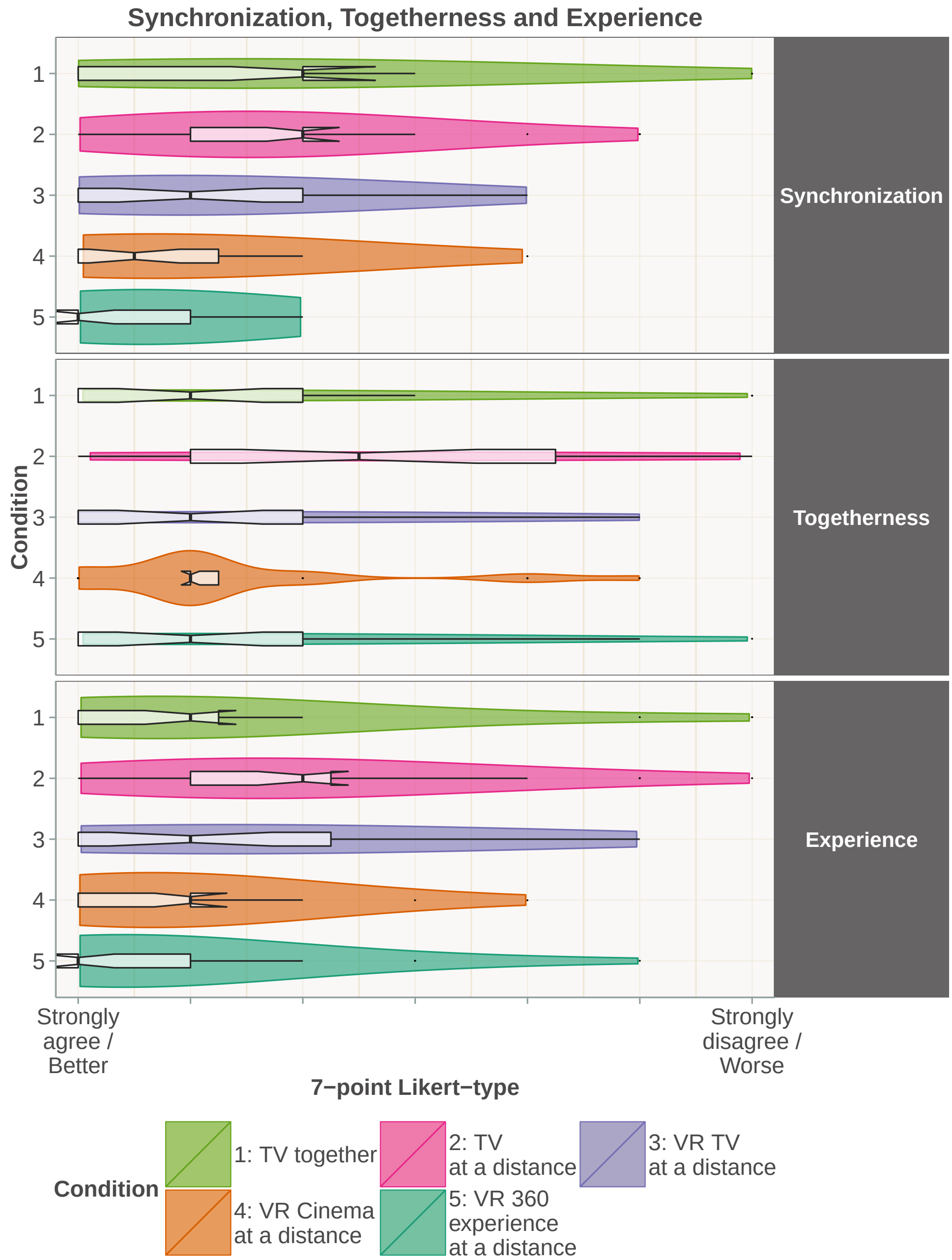


Figure 8.4: Responses for Synchronization [62] ("It felt like our experiences were synchronized", Togetherness ("It felt like my partner and I were interacting naturally, as if we were together" and Experience ("It felt like I was experiencing the activity with my partner") [104].

For rankings (see Figure 8.5), there was a clear preference toward the VR at-a-distance conditions over the TV at-a-distance ($\chi^2(3) = 38, p < 0.01$, *post hoc:* 2-3, 2-4, 2-5, 3-5). Embodied VR communication was preferred to video-mediated communication (Condition 2 versus 3) whilst more immersion was also preferred (Condition 4 / 5 versus 3).

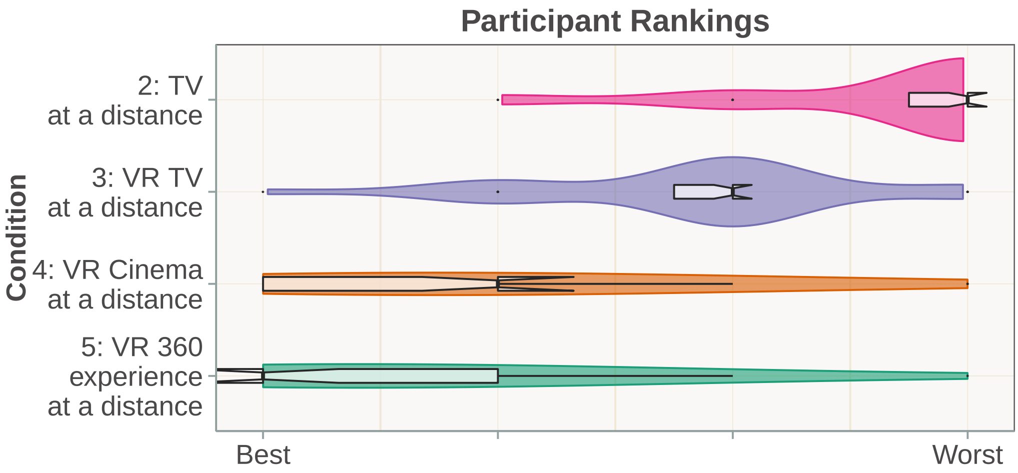


Figure 8.5: Rankings (lower is better) for Conditions 2–5.

With respect to personal media preferences for solo consumption (see Figure 8.6), participants significantly favoured 360° video over viewing in standard video content in reality and in immersive VR environments such as the Cinema setting ($\chi^2(2) = 12, p < 0.01$, *post hoc:* 360 VR Video - TV in VR, 360 VR Video - TV in Reality).

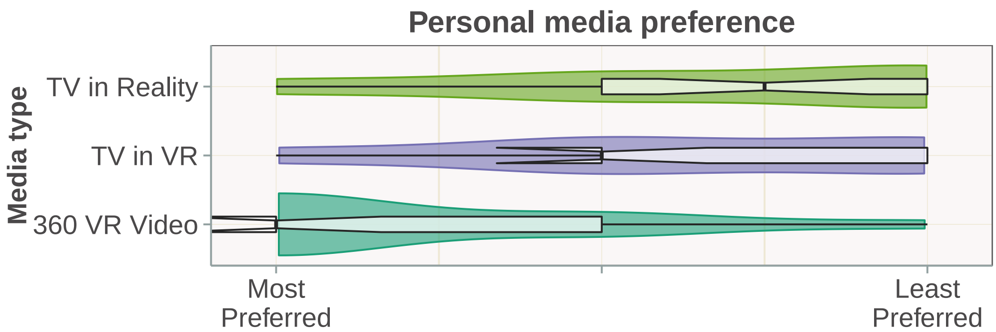


Figure 8.6: Rankings of media types (lower is better).

Responses to a post-study question regarding the likelihood of use of VR indicated that having the capability to socialize in a manner experienced was a strong motivator for adoption of VR use for media consumption.

8.1.2.2 VIEWING (VR ONLY)

Participants' viewing was instrumented, with gaze orientation (Oculus Camera orientation in the 3D engine) recorded at 20 Hz during the VR conditions, to establish the extent to which participants looked at their partner, the virtual media screen (if applicable), and their VR environment. Participants looked in the direction of their partner (see Figure 8.8) the most

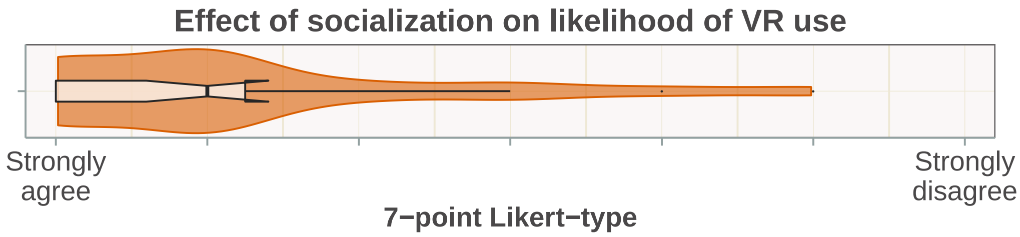


Figure 8.7: Responses to "If more people could be brought into the VR environment at a distance (e.g. watching content together with friends or family), this would make me more likely to consume media in VR."

in Condition 5 (VR 360°) ($\chi^2(3) = 17, p < 0.01$, *post hoc:* 3-5, 4-5), on average for 86 secs (SD=32 secs) compared to 47 secs (SD=39 secs) for Condition 4 (VR Cinema), and 51 secs (SD=41 secs) for Condition 3 (VR TV).

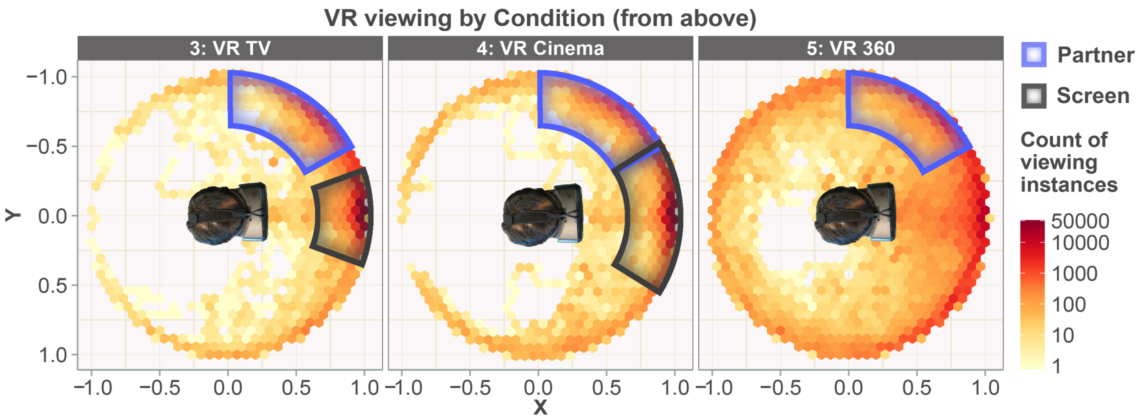


Figure 8.8: Hex bin plot of total viewing instances across participants (as seen from above, with straight ahead for the participant at the rightmost point of the circle, as shown by HMD wearer at (0,0)). Viewing was sampled at 20 Hz, meaning each viewing instance approximately accounts for 50 milliseconds of viewing. Note the log scale for the count of viewing instances.

As can be seen in Figure 8.8, Condition 5 featured the most varied viewing of the 360° space, owing to the immersion and novelty of the 360°video. This, in turn, also caused the most head movement (see Figure 8.9), as measured by cumulative great circle distance[3], meaning that Condition 5 also elicited the most physical effort from participants.

Regarding the amount of effort expended, as measured by the great circle distance of gaze changes, in the VR conditions over time (see Figure 8.10), it can be seen that Conditions 3 and 4 feature approximately the same amount of effort, with relatively little degradation in that effort over the 8 minutes of viewing in each Condition. In contrast, Condition 5 features

[3]The great circle distance is the shortest distance between two points across the surface of a sphere. By iterating through the recorded gaze logs and summing the great circle distance for the unit sphere between the current point of view and the previous point, a measure of the total head movement is established.

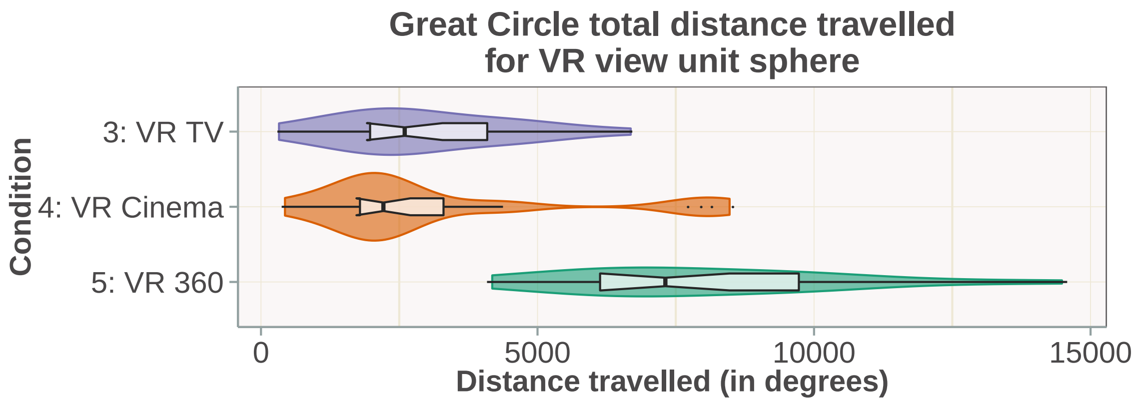


Figure 8.9: Cumulative Great Circle distance between sampled viewing points for VR view unit sphere (rho=1), across participants. $\chi^2(2) = 28, p < 0.01$, *post hoc:* 3-5, 4-5.

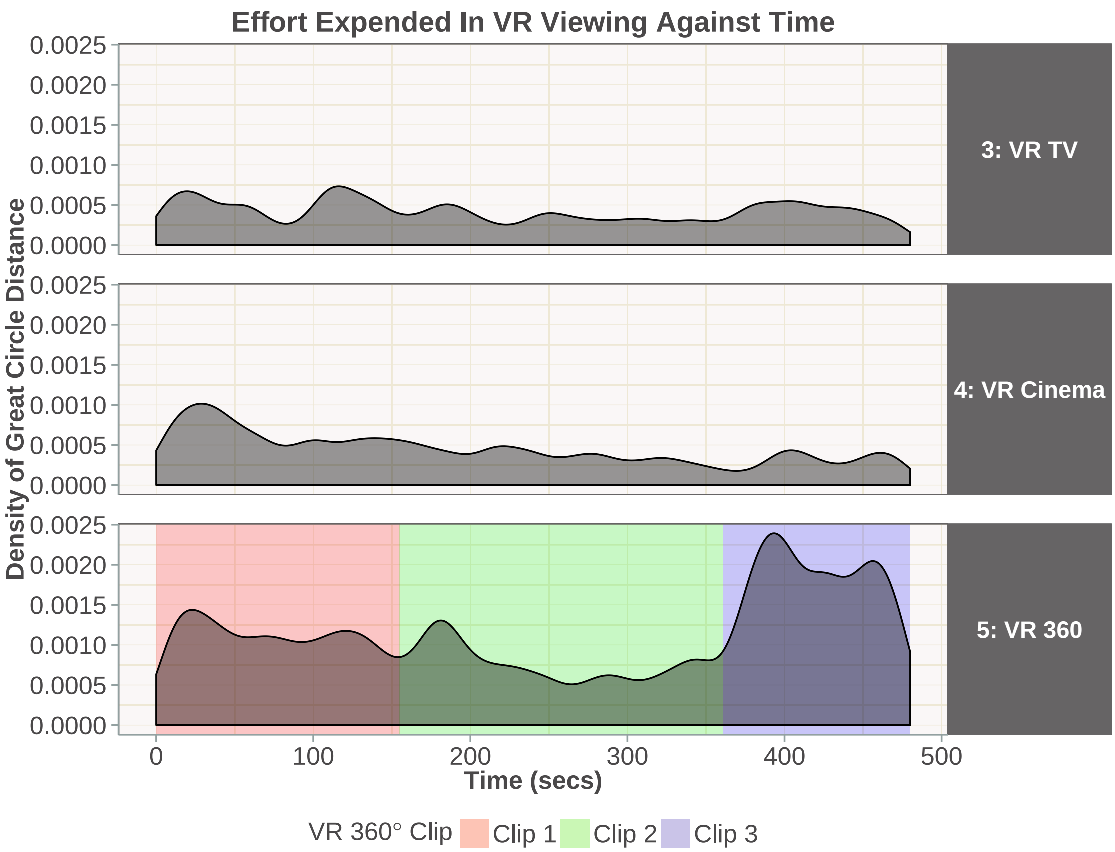


Figure 8.10: PDF of effort expended in VR viewing (great circle distance) over time by Condition. For Condition 5, three clips were used, transitions between these clips are labeled.

a marked increase in effort expended, with effort decreasing over time, and increasing at the advent of a new VR clip. Clip 3 featured a marked increase in effort in comparison to Clips 1 and 2, likely due to the fact that this clip featured significant continuous on-going activity occurring within the full 360° scope of the video (in the form of a number of sharks swimming around the viewer concurrently), in contrast to Clip 1 which featured 360° activity to a lesser degree (occasional sightings of fish), and Clip 2 which primarily featured a single focus of activity (viewing a person engaged in nature activities). These findings suggest that, for short durations at least, as the amount of activity available to attend to in a 360° experience increases, so too will the effort expended in attempting to view the activity. Whilst fatigue may play a role here, as suggested by the decline in viewing activity in each clip, this decline could also be due to the increasing familiarity and thus decreasing novelty of the clips over time.

8.1.2.3 SPEECH

While there was a significant main effect for amount of speech $\chi^2(4) = 11, p < 0.05$ (see Figure 8.11), *post hoc* tests revealed no significant differences between the Conditions, with Condition 5 featuring the highest mean speech of all the Conditions.

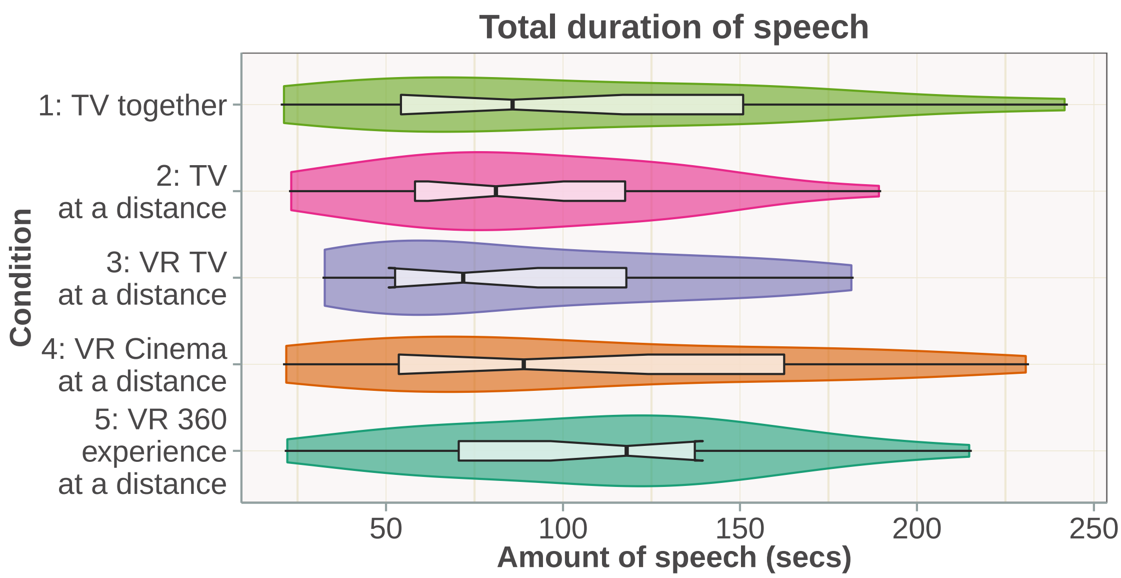


Figure 8.11: Total duration of speech (seconds) across participants.

8.1.2.4 INTERVIEWS

Excerpts from user interviews have been grouped into related discussion themes then broken down by pair (denoted by separators), with each participant discussing the theme quoted.

Regarding RQ 6.3 (socialization), one participant pointed out that their engagement with their partner might not be wholly reflected in viewing data:

> *P2*: I probably looked to him less during the 3D one but we were possibly interacting more because we were saying "aww, look behind you" and stuff, so there's more interaction there as compared to sitting watching TV.

The unfamiliarity of socializing via VR proved difficult for two participants:

> *P22*: It's a bit strange to think you're sitting next to someone, and then like ah, you're not actually sitting next to each other. But I mean maybe it's like Skyping. If you get used to it, then it's like you know that you're not next to them.

> P8: Sometimes if I'm talking to you I look across, but I don't ever look across to check you're there. Because physically you're not there, I don't feel I need to probably do that.

A lack of peripheral awareness of the partner's activity impeded socialization for two participants, but was a useful feature for another:

> *P1*: One thing I didn't like, I wasn't able to see (my partner) at all, I had to move my head... it felt like he wasn't there for me.
> *P2*: You have to turn deliberately, you don't see any of them, they're still either just there and you can see if they gesticulate, or they're not there at all until you move your head to the side.
> *P1*: Because when you are on the sofa with your peripheral vision you can see what's happening.

> *P24*: I liked how in all of them you had to turn round to look at them to see, so you could just choose whether you wanted to (see your partner).

For at least one participant the Cinema context inhibited socialization due to the societal norms attached with viewing in such spaces:

> *P11*: For socializing, I'd say [Condition 3 was the best], I think the cinema is the sort of environment you go there to just to watch things, you don't really socialize, whereas the TV was the more social environment.

Regarding RQs 6.1 (approximating experience when physically together) and 6.2 (exceeding TV at-a-distance), the VR Cinema proved popular for consuming TV media in user rankings, and this was reflected in comments from four participants:

> *P1*: I liked the movie theatre because it was like a physical link together... I felt like I was in the same room as (my partner).

> *P9*: Honestly, I'd watch stuff like that.
> *P10*: It's far better than watching it in [Condition 3]

> *P12*: It gets the experience of being in a Cinema, it felt the same. Like, dark and... If I had popcorn then it'd be good for it.

With 360° video, the majority of participants noted their enjoyment of the experience:

> *P11*: 360° video I really liked, I felt like you were actually there. I've heard the term presence thrown around in VR and I'm starting to kind of understand what that is now, because you kind of feel like you are actually there rather than just watching a TV screen.

However, in terms of utility for at-a-distance use it proved divisive. Five participants suggested that the immersion provided by the 360° experiences impeded their ability to have a shared experience:

> *P6*: The 360 one is too immersive, and you don't want to pay attention to your partner, it's too distracting.

> *P8*: Sometimes you just don't know where to focus, it's like I don't know if I should be focussing on (my partner) or a shark, or the back or the side. If I don't look somewhere it's like I'm going to miss something... it's just another thing you have to look at. Or one other thing to not look at. I don't know if I liked it or not.
> *P7*: It's different though, it's more active, it was something we'd do for short periods of time where you're looking around you and engaged in what's going on... I think it would be exhausting watching a VR movie where there's also something that could grab your attention, but you don't know where it is, like (my partner) said.
> *P8*: And if you don't look, you've kinda missed it. Whereas if you look at a TV, everything is always in front of you, you can't really miss content.

P11: There was too much going on in 360, you couldn't watch a movie in it because you'd be looking about constantly, (whereas) the VR cinema was just there.

P23: The 360 one is kind of hard because you wouldn't really watch a lot of TV like that... you'd always feel like you are missing something. It would have to be something like the ones that you showed us... it's just something's happening around you, like an experience.

8.1.3 DISCUSSION OF EXPERIMENT 8 AND RESEARCH QUESTION 6

Research Question 6 asked:

> How are VR HMDs likely to change the nature of synchronous media consumption at-a-distance?

To answer RQ 6, three sub-questions were asked:

RQ 6.1 To what extent can VR HMDs approximate the experience had when physically co-viewing together?

RQ 6.2 To what extent can VR HMDs exceed the experience had when co-viewing together using the TV at-a-distance?

RQ 6.3 Will the immersion provided by VR experiences help or hinder socialization at-a-distance?

The findings of this Experiment suggest firstly that, for communications functionality alone, VR HMDs offer a better experience to those at-a-distance than PiP TV at-a-distance, as evidenced by the differences between Condition 2 (TV at-a-distance) and Condition 3 (VR TV at-a-distance) where the size of the display, and the environment were controlled, answering RQ 6.2. Whether this would hold true when compared to Conditions designed around the off-TV proxy placement of VMC found in [133] and the CastAway prototype remains unclear, and will require further work to establish. However, given that PiP as utilized by [133] was preferred by users, it is likely that embodied communications using VR provides greater feelings of closeness compared to both PiP and off-device VMC. With respect to RQ 6.1, there were no statistically significant differences between Condition 1 (baseline) and Condition 3 (VR at-a-distance), suggesting but not confirming that the at-a-distance Condition in some ways approximated viewing together physically.

Regarding RQ 6.3 and the effect of immersion on socialization, whilst there was no effect in terms of the amount of speech, there was an effect in terms of the total viewing of partners, with viewing significantly increasing in Condition 5. However, this discrepancy could be accounted for by the fact that participants may not have been intending to look at their partner, but instead their virtual environment. Because of this, the awareness gained through this viewing may be questionable, given that participants may have predominantly been attending to the 360° environment. This is hinted at in the Social Presence scores, with mean Social Presence being lower in Condition 5 compared to Condition 4, but is not proven as the difference was not statistically significant. More broadly, employing more immersive environments improved Social Presence, Immersion, And Enjoyment, demonstrating that for at-a-distance consumption, both Cinema-like and 360° experiences have significant merit.

The instrumented increase in viewing in the 360° experiences of Condition 5 may, however, pose a more concrete problem for synchronous co-consumption. Over the 8 minutes of viewing, the average effort expended in viewing in Condition 5 was over double that of Conditions 3 and 4. Firstly, from a purely physical standpoint, this increase in effort in 360° experiences is likely less sustainable over long periods than the effort expended in fixed-focus experiences (e.g. the TV and Cinema experiences of Conditions 3 and 4). Thus, for regular and lengthy at-a-distance communication, 360° experiences may prove impractical. There is a counter-argument to this point: that users will self-regulate their amount of effort and manage their physical workload appropriately. However, if left to do so, their enjoyment of the 360° experience will likely be negatively impacted. Feedback from participants suggested that VR media requires a high level of engagement, as to not engage with it in this way would lead to continual feelings of missing activity occurring out of view. Indeed, perception of Condition 5 was negatively affected for a small subset of users, given the interview responses regarding fears of missing content.

To make 360° content suitable for long-term, longer-duration synchronous co-consumption, on the basis of these results research needs to be conducted regarding the maximum sustainable viewing effort, and in gaining an awareness of what others are attending to in the VR experience. Regarding maximum sustainable viewing effort, this is analogous to terminology used in exercise (e.g. maximum sustainable heart rate), where there is an understanding that there are physical limitations which must be managed in order to prevent burnout or exhaustion. By understanding the physical limitations of the VR HMD viewer, viewing effort could be regulated. This could be facilitated in a number of ways. For example the rendering, or creation, of 360° content which allows for ebbs and flows between recovery periods. Or where a single focus of attention is provided or emphasized, versus higher engagement periods where multiple activities occur around the viewer.

Viewing effort could also be regulated through additional cues for helping the user focus on an event. And designed for in terms of managing viewing virtually (e.g. using a game controller to move the view explicitly) or through physical actuation (e.g. SwiVRChair [78]) thus reducing physical effort. Such efforts will likely also have importance regarding solo consumption of 360° content, given early indications that the amount of effort involved may be problematic[4].

Increasing connectedness with others in the experience is also likely worthwhile. For example, if the user knows s/he is attending to the same area of the experience as the partner (such as in [92]), they may feel reassured they are not missing out on other parts of the experience. Future research might quantify the amount of effort expended longitudinally as ownership of VR HMDs becomes mainstream, and the extent to which fatigue affects adoption and usage, and would be aided in doing so by this chapter providing a baseline and novel analyses to rely upon.

8.2 CONCLUSIONS

In this study it was demonstrated that consumer VR HMDs could change the way in which people consume media together and communicate at-a-distance. Participants significantly preferred immersive and shared VR environments over traditional picture-in-picture co-viewing, with results broadly comparable to viewing together. Immersive 360° video proved popular with participants, but so too did a virtual Cinema environment, providing new-yet-familiar ways to be immersed in existing content in the home. However, more importantly, these technologies also provide the means to change *who* content can be viewed with, allowing users the possibility to sit next to their partner once more, at-a-distance, and experience their reactions to a a film or TV show much as in reality. Whilst this is only an approximation of the experience had when physically together, this study suggests that in many cases it would be significantly preferable to existing VMC, and this preference might well be amplified if given the capability to incorporate more people at-a-distance into these shared experiences.

Given the results from Experiment 8, the answer to Research Question 6 is that it is highly likely that VR HMDs will change the nature of synchronous media consumption at-a-distance, given their capability for more immersive experiences, and mixed reality embodied commu-

[4]e.g. the experience of early attempts at VR films at the Sundance Film Festival '16 , where one reviewer suggested that "damning issues... were common across the films: the need to make me, the viewer, take on the additional burdens of director and cinematographer", see http://arstechnica.co.uk/the-multiverse/2016/02/sundances-vr-films-fail-by-passing-the-workload-buck-to-their-viewers/

nications, both of which were preferred by users over PiP TV at-a-distance as previously examined in literature.

9. Discussion and Conclusions

This thesis has investigated new and novel ways by which TV and VR displays can better support collocated and at-a-distance experiences. In Chapter 1, the thesis statement was as follows:

> This thesis asserts that TVs and VR HMDs can better support social and shared use, in both collocated and at-a-distance contexts. For collocated TV, this thesis demonstrates that the TV can be augmented to support multi-user interaction, enable independent and shared multi-user use, and provide an awareness of the multi-screen activity of those in the room. For at-a-distance TV, shared activities can be enabled using existing smart TVs and smart phones, broadening the scope of shared experiences beyond the four walls of the home. For VR HMDs, collocated proximate persons can be brought into mixed reality VR experiences based on engagement, improving VR HMD usability. Applied to at-a-distance interactions, these shared mixed reality VR experiences can provide more immersion, and allow for socialising that more closely resembles viewing together in person, compared to at-a-distance TV.

The thesis statement and the following six Research Questions have been addressed in this thesis:

RQ1 - Chapter 3 Are existing single-user TV interfaces suitable for multi-user use?

RQ2 - Chapter 4 How can TVs support both shared and independent use?

RQ3 - Chapter 5 Can TVs provide an awareness of others' collocated multi-screening activity without disrupting existing usage?

RQ4 - Chapter 6 How can TVs support synchronous at-a-distance use with a partner?

RQ5 - Chapter 7 Should VR HMDs provide the ability to be aware of, and engage with, others in the same room, and how?

RQ6 - Chapter 8 How are VR HMDs likely to change the nature of synchronous media consumption at-a-distance?

These six questions have been addressed through a review of the related literature and a series of surveys and studies evaluating collocated and at-a-distance TV and VR use, in both laboratory settings and in-the-wild. This chapter summarises the work reported in this thesis, and discusses how the novel findings and contributions contained answer the six Research Questions. Limitations of this research are discussed, along with prospective future research regarding collocated and at-a-distance use of TV and VR displays. The chapter ends with a final summary of the conclusions and contributions of this thesis.

9.1 THESIS SUMMARY

Chapter 3, *Shared Control of the TV*, reported on an "Existing Behaviours Survey" (Section 3.1) examining how control of a shared TV is currently managed. This exploratory survey established the use of, and preference for, a set of behaviours as occurring when sharing use of a physical remote control and thus control of a TV interface, through turn taking, passing control, taking control, and hierarchical control. These behaviours, along with other potential behaviours given the possibility of concurrent and simultaneous interaction, were then virtualized and implemented in a multi-user system for navigating an existing single-user, grid-based EPG.

Experiment 1 (Section 3.2) then examined the application of these behaviours to shared browsing of an existing single-user, grid-based Electronic Programme Guide in small intimacy groups. This experiment found that using a subset of the virtualized "one user" behaviours, namely passing, taking and lending control, could facilitate multi-user usage whilst preventing the destructive interference that would occur if everyone could interact concurrently.

The contribution of this chapter was in demonstrating that existing TV interfaces have the potential to be opened up to multi-user use, without necessarily having to transition to new interactions such as multi-pointer or multi-cursor UIs, split-screen interfaces, offloading interactions to other devices or screens, or mediating control through proximity or attention. Instead, control can be virtualized and mediated through social behaviours rooted in the existing sharing of the remote control. This chapter answered RQ 1.

Chapter 4, *Shared Use of the TV*, reported on Experiments 2 and 3, examining how multi-view display technology (meaning a separate physical view for each user) could be used to allow for both independent and shared use of a TV.

Experiment 2 (Section 4.1) examined the design of a multi-view TV interface by comparing an Android-based two-user smart TV against both multi-screen and multi-view displays in a collaborative movie browsing task. This Experiment found that a multi-view TV interface, where users could transition between or temporarily peek at two available virtual views, was preferable to a single-view TV interface. However, in a comparison of multi-view TV to two physical displays, there was a marked difference not in how well users perceived their ability to collaborate or gain awareness of each other's activity, but in how awareness was accomplished. The two physical displays were used to facilitate a casual and continual awareness of the activity of the other participant, with views lasting for approximately 3.1 seconds in the two physical views condition, compared to 13.6 seconds in the multi-view condition. In the two display condition, users chose to manage their awareness through a multitude of shorter glances at each display. In contrast, the multi-view condition featured much longer views of each virtual view, indicating that the transition and peek behaviours provided did not adequately encapsulate the desired means of maintaining awareness.

Based on these findings, Experiment 3 (Section 4.2) iterated upon Experiment 2 by giving multi-view users the ability to transition between casual (viewing both views) and focused (viewing only one view) modes of usage. In addition, users could dynamically set their engagement with another user's activities, meaning that when in the casual mode the user could arbitrarily divide their personal physical view between the available virtual views at whatever ratio they desired. This experiment showed that users dynamically varied awareness of their partner's activity, the majority of the time dedicating between 7% and 43% of the display to this, but occasionally dedicating the majority of the display to awareness, whilst either retaining the ability to interact, or forfeiting interaction entirely by making the interactive view essentially non-visible. Moreover, users still employed the "transition" management behaviour in both casual and fullscreen / focused modes, with some users reporting that, in the fullscreen mode, having the ability to transition between views was conveniently like having a "previous channel" button.

The contribution of this chapter was in the foundational design of a multi-user, multi-view smart TV that could support shared, collaborative and independent activity on a single shared TV, and establishing the importance of supporting casual awareness of others' activity. This chapter answered RQ 2.

Chapter 5, *Appropriating the TV for Multi-Screen Activity*, described Experiments 4 and 5, firstly examining how awareness of multi-screen activity (i.e. mobile / tablet devices) could be provided through the TV, and secondly examining how disruptive such usage of the TV would be to existing viewing, and how awareness of ongoing activity in the same space could be provided non-disruptively.

Experiment 4 (Section 5.1) looked at the extent to which multi-screen activity can be made more accessible to others, through utilizing the TV as a shared focal point upon which multi-screen activity can be displayed. It found that through a basic set of behaviours for managing mirrored use of the display, namely the ability to request ownership of the display from whomever was currently mirroring their device, or take use of the display, a shared screen mirroring system could better facilitate collaboration and content sharing in small groups, resulting in greater equity of participation and awareness of others' activity compared to both device-only usage, and having one device permanently mirrored to the TV (reflecting the cost of pairing a device in typical Miracast/Airplay screen mirroring technologies at the time). Indeed, this design in-part reflected the eventual use of screen mirroring on the Google Chromecast platform, where clients could take mirrored use of the display at any time. Moreover, utilizing the shared display provided a shared focal point for the group; incidence of two and three person co-viewing increased dramatically in the shared display Conditions, providing users with a shared reference point which likely aided in the communication and discussion necessary for effective collaboration, as suggested by the users' perceived ability to collaborate. This represented an additional benefit regarding utilizing the display over, for example, tablet or mobile devices for providing awareness, as the shared display typically provides a reference point accessible to anyone in the room.

Experiment 5 (Section 5.2) built upon Experiment 4 by investigating how disruptive shared, mirrored usage of the TV display could be to existing TV viewing, and examined ways to mitigate this disruption given a multi-view capable TV, allowing for non-disruptive awareness of multi-screen activity occurring in the same room. It found firstly that fragmentation of TV content viewing was at its highest in the shared screen mirroring approach from Experiment 4. Screen division minimized this fragmentation and disruption, but at the cost of potentially attending to multiple content streams on the TV at once, increasing perceived workload. This effect could be minimized by inferring focus on particular content streams e.g. focussing on a stream when it had both audio and video activity, suggesting that for single-view displays, screen division combined with inferred focus offered a means of sharing multi-screen activity on the TV whilst minimizing disruption.

For multi-view TVs, Experiment 5 found that passive screen mirroring (i.e. selectively choosing to attend to other devices' activity) was the best Condition with respect to distraction, control over awareness, independence and user ranking. In essence, having the ability to independently choose what to attend to was preferable to the single-view inferred focus TV condition. However, there were significant issues still to be resolved regarding the acceptability of passively making device activity available to be viewed by others. A post-study questionnaire demonstrated that, for such a system to be deemed acceptable to users, controls over when the device was to be made available to be viewed would have to be implemented, regardless of any further developments in screen-mirroring technology such as automatic privacy filtering, and regardless of whether the device was personal or shared with others in the household.

The contribution of this chapter was, firstly, in establishing the benefits to collaboration of using the TV to share multi-screen activity and, secondly, in examining how multi-screen activity could be shared and viewed on a TV whilst minimizing disruption regarding others usage of the TV and minimizing workload regarding management of the display. This was achieved for single-view TVs through screen division with inferred focus, and for multi-view displays through passive screen mirroring. This chapter answered RQ 3.

Chapter 6, *Synchronous At-A-Distance Use of the TV*, described the implementation of an at-a-distance synchronous co-viewing application, called CastAway, on an existing smart TV platform, Google Chromecast. This implementation was software only, and enabled at-a-distance functionality transparently for existing Chromecast applications, as well as providing communications functionality to users, and was achieved through the interception of Chromecast APIs.

Experiment 6 (Section 6.2) then deployed CastAway in-the-wild to five couples at-a-distance for week-long evaluations, with couples having the capability to consume TV and Music content at-a-distance. Perceived togetherness, frequency and quality of communications, and qualitative feedback all strongly indicate the merits of smart TVs supporting at-a-distance experiences. This evaluation also indicated that there is significant value in enabling the consumption of other media types synchronously at-a-distance. The examination of Music found that, where tastes in Music are aligned, it can offer a shared backdrop to users which is, in many cases, just as effective as TV content, allowing couples to feel closer to each other whilst engaging in other activities. Communication whilst consuming media at-a-distance was also examined. Whilst prior literature has emphasized that video-mediated communication was the preferred and primary means of communication at-a-distance, reinforcing closeness and presence in the process, for four of the five couples Text chat was significantly preferred. Finally, the number of attempts to re-synchronize TV video streams was low, and often significant delays were tolerated by users, with seemingly little effect on perceived synchronization for the system as a whole. Qualitative interview data indicated participants had a strong preference toward continued use of CastAway.

The contribution of this chapter was in demonstrating that an existing smart TV platform could support at-a-distance experiences, and in evaluating synchronous at-a-distance media consumption and communication in-the-wild, instrumented to a level of detail that had previously been impossible in prior research. This chapter answered RQ 4.

Chapter 7, *Usability Of VR HMDs*, examined the usability of existing consumer VR HMDs in light of their anticipated adoption in the home, potentially supplementing or supplanting the TV for some viewing. This chapter firstly described a survey (Section 7.1) into the significance and prevalence of usability impediments to VR HMD use, such as being unable to see interactive objects or proximate persons. It found that an awareness of proximity and presence of others in a shared space was strongly desired by existing VR HMD users. Section 7.2 then provided an overview of a generalized solution to some of these impediments, in the form of Engagement-Dependent Augmented Virtuality, where reality can be selectively incorporated as and when necessary based on inferred user engagement with that reality.

Experiment 7 (Section 7.3) then examined how the concept of Engagement-Dependent Augmented Virtuality could be applied to the presence of others in the same room, providing a lower-engagement awareness of proximate persons. Assuming a high-engagement state to be the fully realised presence of the proximate person in VR, a low-engagement state was evaluated whereby a transparent silhouette of the proximate person was incorporated into VR. However, the low engagement state, while providing decreased awareness, failed to be significantly less distracting than the full engagement state. Thus, it did not meet the criterion of the required low engagement state, which would be expected to facilitate some awareness, with significantly less distraction than full engagement. Participant interviews suggested that the lesser, or more casual, state of awareness could incorporate more abstract visual and non-visual representations of proximity and existence, not necessarily tied to gaze e.g. augmenting the virtual environment, or using textual alerts such as are employed in messaging and multi-player gaming.

The contribution of this chapter was, firstly, in establishing the usability impediments to VR HMD use, specifically related to VR users being unable to perceive elements of reality. And, secondly, this chapter contributed an investigation regarding how proximate persons could be incorporated into VR whilst minimizing disruption to the VR HMD wearer's sense of presence in VR. This chapter answered RQ 5.

Chapter 8, *At-A-Distance Media Consumption Using VR HMDs*, described Experiment 8 (Section 8.1), examining how VR HMDs could enable shared and synchronous at-a-distance VR experiences. Shared immersive experiences were compared to physically co-viewing together, and co-viewing together at-a-distance using the TV for both viewing and communication. This experiment found that for communications functionality alone, VR HMDs offer a better experience to those at-a-distance than Picture-in-Picture TV at-a-distance, whilst more immersive VR environments improved Social Presence, Immersion, and Enjoyment.

However, 360° experiences are ill-suited to at-a-distance co-viewing for a small subset of users, due to a lack of a shared focus of attention, combined with significantly more stimulii to attend to. Moreover, whilst users exhibited a significant preference for 360°media compared to consuming TV in reality and TV content in VR, 360° experiences were also found to necessitate significantly more effort to view than TV content in VR, which may present a significant impediment to longer term usage.

The contribution of this chapter was a novel comparison of TV together, TV at-a-distance, and VR at-a-distance across varying levels of immersive experiences. This comparison found that mixed reality VR at-a-distance was significantly preferred to TV at-a-distance for synchronous at-a-distance media consumption, and that users significantly preferred 360° media compared to TV in reality and TV content in VR. However 360° VR content requires more effort to consume, and this may present an impediment to longer term / duration usage that will require further research. This chapter answered RQ 6.

9.2 RESEARCH QUESTION ANSWERS, LIMITATIONS AND FUTURE WORK

9.2.1 RESEARCH QUESTION 1

Are existing single-user TV interfaces suitable for multi-user use?

Research Question 1 was answered in Chapter 3, *Synchronous Control of the TV*. The survey in Chapter 3, combined with the prior literature review, suggested that this question broadly resolved to comparing concurrent and mediated interaction. Specifically, would users self-regulate their interactions to avoid interference? Or could some combination of the system and the users regulate concurrent interaction effectively, allowing for every user to have some level of control at all times. Or was the constraint of one user only interacting at any one time, imposed by there typically being only a single physical remote, fundamental to interaction with a typical TV interface designed for one user at-a-time interaction.

Experiment 1 found that the latter was the case; the constraint of one user interacting at any one time was fundamental in the case of grid-based EPG browsing, with users unable to self-regulate their interactions to avoid interference, and approaches to managing concurrent interaction being perceived poorly compared to the control of managing a single physical remote. However, virtualizing control such that the behaviours for managing a physical remote control were enacted digitally, across multiple phone-based remote controls, was successful in allowing for multi-user use of a single-user TV interface. Whilst this stands to reason, given that the physical actions of managing a remote control were replaced with virtual actions, this opens up a number of possibilities with respect to how multi-user interaction is governed for such interfaces. By moving away from the physical management of a remote control and embracing virtualized means of managing control, a variety of input modalities could be used to interact with existing TV interfaces (e.g. multiple remote controls, mobile phones with IR support, remote apps, gestural controls) whilst preventing the possibility of destructive inputs (e.g. both attempting a navigational event). This is especially relevant for grid-based navigation, such as is still used in a variety of smart TV interfaces (e.g. Android TV).

Overall, this thesis concludes that existing single-user TV interfaces, specifically those based on discrete grid-based single-cursor interaction, are suitable for multi-user use only when the constraint of "one user at-a-time" interaction with said interface is upheld.

9.2.1.1 LIMITATIONS AND FUTURE WORK

This approach does however have some notable limitations that could only be understood through further research. Firstly, appropriate interactions to enable the management behaviours must be designed for any given interaction modality. For example, how can control be passed or taken gesturally? Secondly, extensions to this work that would require less user-based management should be investigated. For example, if a user has not interacted in some time, can the system assume or infer that they are no longer interacting, or have them relinquish control automatically? Can certain user inputs and modalities be prioritized?

Establishing the generalisability of this approach e.g. what tasks are suited to more simplistic single-user interactions (and thus are suited to mediation of control schemes) would also aid in designing multi-user smart TVs whose more basic or ubiquitous functionality is still readily accessible to users of all ages and capabilities. Navigation, 1-dimensional controls (e.g. volume or channel switching), or contexts where the complexity of higher bandwidth input controls (such as pointer input) is unnecessary (e.g. grid-based views navigated via cursor) might all be areas where mediation of control is of use, allowing non-disruptive shared multi-user use of a standard single-user TV interface.

Mediation of control might also provide additional social benefits, for example being able to take control from children, or have parental inputs prioritised, that would be worth investigating in longitudinal studies in the home. Conversely, the additional management required by mediation of control might render interfaces designed from the ground up for multi-user use and interaction preferable. In essence, whilst single-user TV interfaces can be made suitable for multi-user use, future work would have to establish in what contexts this is preferable.

9.2.2 RESEARCH QUESTION 2

How can TVs support both shared and independent use?

Research Question 2 was answered in Chapter 4, *Shared Use of the TV*. Traditionally, shared use of the TV had been enabled through screen-division approaches, however such techniques inevitably compromise use of the display for those in the room, with no one user being able to attend to the entirety of the display, and visual distraction introduced for all. Whilst RQ 1 examined shared use, it did so for grid-based interfaces only, with no capability for facilitating independent use. Thus, the basis for answering this Research Question was rooted firstly in examining the future of TV displays from a hardware perspective. Glasses-free 3D TVs relying on lenticular displays are slowly approaching consumer availability, while active shutter-based 3D TVs are already widely available for consumers. In both cases, the display technology allows for multi-view use, where each user has the potential to perceive a different physical view to others in the room.

Given the existence of consumer multi-view TVs, the answer to Research Question 2 lay in how these displays could be used to support both shared and independent use, through separate physical views for each viewer, made up of whatever virtual activity was being undertaken. Experiment 2 resulted in the design of a two-user, two-physical-view multi-view display which superficially answered RQ 2 by being capable of supporting shared interaction, with users attending to the same virtual view and interacting using a multi-pointer interface, and independent use, with users able to attend to separate and distinct virtual views. However, successful collaboration depends upon maintaining awareness of the actions and activities of others, and in this respect the design of the multi-view display in Experiment 2 was insufficient, with no support for casual, glance-based awareness.

Experiment 3 resulted in a multi-view display that could also support casual, glance-based awareness, allowing for independent activity whilst maintaining the desired level of awareness of others' activities, through a dynamic split-screen approach. Thus, the design of the multi-view TV in experiment 3 best answers RQ 2, supporting the full gamut of shared, collaborative, and independent activity on a single display.

Overall, this thesis concludes that TVs capable of multi-view rendering (i.e. being able to provide a separate physical view to each viewer) can support shared and independent use through the means by which virtual views are rendered for each viewer. Transitions between virtual views, quickly switching between relevant virtual views, and maintaining a casual awareness of others' activity are all important features if a multi-view display is to support shared, collaborative and independent use without disrupting others' usage.

9.2.2.1 LIMITATIONS AND FUTURE WORK

With respect to future work, examining the usage and effect of multi-view displays across different collaborative tasks might have a significant impact on the results, and thus the contexts in which multi-view might prove most useful. There is also the issue of effectively using the physical display area when in casual awareness mode. The approach in this thesis involved scaling virtual views whilst preserving aspect ratio, resulting in parts of the screen being under-utilized. For certain types of content (e.g. video) it may, however, be acceptable to truncate this content, presenting only a portion of the virtual view sufficient to provide awareness whilst maximizing usage of the screen. Similarly, there may be ways of communicating sufficient awareness in a more discrete and unobtrusive fashion e.g. textually.

There are additional questions regarding scale and appropriation: in scaling the interactions up to support more than two views, and more than two users, how many views / users are manageable before the complexity undermines the benefits of such a TV? And what kind of social impact might such a display have in the home? Would users transition from devices to the more shareable TV for some subset of their activities? Answering these would require longitudinal deployment and the availability of HD, glasses-free multi-view displays, which means this is not a near-term possibility, and may necessitate revisiting this work once a number of years has passed. Finally, for multi-view to work across a breadth of media tasks, solutions will be required to either help users in managing a shared audio space (preventing potentially frustrating conflicts), or provide personal and private audio spaces in an acceptable manner (i.e. excluding previously used solutions such as in-ear headphones that impact socialization).

9.2.3 RESEARCH QUESTION 3

Can TVs provide an awareness of others' collocated multi-screening activity without disrupting existing usage?

Research Question 3 was answered in Chapter 5, *Appropriating the TV for Multi-Screen Activity*. Experiment 4 found that using the TV as a means of sharing multi-screen activity was beneficial to collaboration compared to sharing activity physically via device views. This shared screen-mirroring was facilitated through basic behaviours for managing ownership of the display, in the form of passing and taking the display, influenced by Experiment 1. However, this experiment had some notable limitations. Firstly, there was no on-going activity on the TV (i.e. there was no emulation of existing viewing), and secondly only one device at-a-time could be mirrored. Thus, whilst this experiment answered RQ 3 in-part, it did not address the "without disrupting existing usage" clause.

Experiment 5 built upon this by applying screen-division to the problem. This resulted in two answers to this Research Question, one for single-view TVs and one for multi-view TVs. For single-view TVs, screen-division combined with a means of inferring focus to aid users in managing use of the display proved best, being the epitome of active screen mirroring (i.e. users actively choosing to mirror their device to the TV) whilst allowing for uninterrupted viewing of existing TV content. However, passive screen mirroring (i.e. users being able to selectively attend to the device activity on-going around them using a multi-view display) was more preferable still by removing the presence of content and activities users did not wish to attend to (e.g. their own device activity).

Overall, on the basis of Experiment 5 this thesis concludes that TVs can provide an awareness of others' collocated multi-screening activity whilst, at worst, minimizing the disruption to the existing TV usage of others, and, at best, preventing disruption entirely. This was achieved for single-view TVs through screen division with inferred focus, which minimized disruption to others existing usage by both dividing the TV display to allow for multiple activities to be viewed concurrently, and pausing existing viewing of TV content when said viewing was conflicting with audio-visual mirrored activity. For multi-view displays, disruption was prevented through passive screen mirroring using a multi-view display, allowing each user to attend to whichever activity they so wished.

9.2.3.1 LIMITATIONS AND FUTURE WORK

Firstly, as with Research Question 2, there is the issue of scaling systems up to support more users, and examining the impact this might have on user preferences regarding shared use of the TV. In introducing more devices and more users, it is likely that a more sophisticated means of inferring focus will be required to help users manage use of the TV, and thus minimize the workload and frustration involved in utilizing such functionality. It is also possible that the screen-divided use of the display may prove unacceptable in such cases (with acceptability likely tied to the size of the display and the extent to which screen-division is employed), requiring the system to fall back to usage comparable to Experiment 4. There is also the potential for screen-mirroring applications outside of the TV, much as device mirroring was brought to VMC [27], for example enabling device-to-device mirroring, and the application of some of the concepts discussed regarding TVs being applied to, say, larger tablets, where their screen size might allow for some form of casual awareness without disrupting the primary activity on the device. The unaddressed issue of reciprocal control also remains; thus far, devices have been treated as read-only portals into the activity of others, but there is no technological barrier to there being input provided back to the device from others, however there may be significant social barriers to doing so.

Finally, there is the idea of inferring what to present on the TV, what activity to focus on, and when. Given the plethora of devices and activities available, it is likely that TVs operating in conjunction with devices might be able to significantly expand interaction with, and awareness of, others in the household. This work has demonstrated how awareness can be significantly enhanced, but at a cost of increased user workload for example, and thus TVs must become smarter and more able to assist users in making them aware of what is happening around them.

9.2.4 RESEARCH QUESTION 4

How can TVs support synchronous at-a-distance use with a partner?

Research Question 4 was answered in Chapter 6, *Shared At-A-Distance Use of the TV*, which expanded the scope of this research beyond collocated experiences and into shared and synchronous at-a-distance experiences. At-a-distance TV consumption has been previously demonstrated as being effective in supporting long-distance relationships. Given this, Research Question 4 aimed to examine whether existing smart TVs could support users in engaging in at-a-distance media consumption. By intercepting the APIs of the Google Chromecast platform, a proof of concept was developed whereby Chromecast applications could transparently operate across multiple Chromecast devices at-a-distance, called CastAway. By proving the technical feasibility of CastAway, RQ 4 was in-part answered. However, to understand the efficacy of this approach for synchronous at-a-distance media consumption, a further evaluation was required in the form of Experiment 6, an in-the-wild study of five couples usage. This proved that CastAway was effective in enabling synchronous TV and Music consumption, and thus that the Chromecast platform could transparently support synchronous at-a-distance usage, with relatively low cost in terms of implementation and end-user adoption, and no cost in terms of modifying existing applications to support at-a-distance usage.

Overall, this thesis concludes that the Google Chromecast TV platform and, by extension, Android TV can support synchronous at-a-distance use with a partner, and that there are few impediments to bringing synchronous at-a-distance experiences to those geographically separated from their partner, friends or family. This thesis affirms that given this finding, TV platform manufacturers should re-evaluate their lack of support for synchronous at-a-distance usage.

9.2.4.1 LIMITATIONS AND FUTURE WORK

Regarding the limitations of this work, firstly there is the applicability of the approach used here to other smart TV platforms e.g. Apple TV[1] or Amazon Fire[2]. The Chromecast platform is uniquely suited to the approach taken for the CastAway system, due to the fact that client devices drive the TV experience. As such, this platform requires mobile devices (which typically have front-facing cameras and microphones). However, more importantly, due to the reliance on issuing commands to the Chromecast-enabled TV that encapsulate what TV activity should occur (e.g. what application is being used, what content is being viewed etc.), this leads to relatively straightforward management of the current state of all connected TVs. This is not shared with TV platforms that use more traditional discrete remote controls for input. In cases such as Apple TV or Amazon Fire, at-a-distance functionality would likely have to be incorporated into the applications being used, rather than being incorporated transparently to said applications. However, whilst this increases the difficulty of providing generic support for synchronous at-a-distance TV experiences, the problem resolutely remains a software one, with the capability for communicating via the TV possible (albeit audio only, for example using the microphone in the Amazon Fire TV remote or Apple TV remote), and the hardware being internet-connected.

Commercial implementation of CastAway would undoubtedly face significant challenges, for example in ensuring all in a Chromecast session have adequate rights for the media being consumed, and designing for scalability across more than two people or more than two households (e.g. in terms of how VMC is facilitated [231]). In scaling across more households, the loose-synchronization approach may prove increasingly useful in preventing frustration due to re-synchronization. Furthermore, the role of re-synchronization needs to be examined longitudinally in-the-wild. Is automatic re-synchronization a necessity only when communicating via video chat? In light of the findings in this thesis, existing guidelines may be too prescriptive, and thus further examination of when, and to what extent, re-synchronization is required is necessary.

Future work could also examine the suitability of other applications and media experiences to consumption at-a-distance, as well as comparing in-the-wild device-based communications with Picture-in-Picture / TV-based communications. If support for a wider range of Chromecast applications could be established (e.g. games, productivity apps, various media services etc.), a longer-term deployment (i.e. lasting months) would be advisable, in order to give users the opportunity to appropriate the display for less frequently occurring synchronous experiences (e.g. trip planning, sharing photos) and establish the extent to which the TV could become a shared portal for activity at-a-distance. This could lead to loosening

[1] http://www.apple.com/uk/tv/

[2] http://www.amazon.co.uk/s/?ie=UTF8&keywords=amazon+fire+box+tv

the "synchronous" constraint of the at-a-distance TVs, for example allowing user A to cast content only to user B's TV, and *vice versa*, turning the TV into a space for sharing device activity with others at-a-distance without necessarily replicating what is rendered on both user A and user B's TVs.

9.2.5 RESEARCH QUESTION 5

Should VR HMDs provide the ability to be aware of, and engage with, others in the same room, and how?

Research Question 5 was answered in Chapter 7, *Usability Of VR HMDs*, which examined the usability of VR HMDs given their imminent anticipated adoption in the home. This Research Question was answered firstly by validating that the presence and proximity of others was a usability concern for existing VR HMD users through a survey. And secondly, by examining how this awareness could be communicated to VR users in Experiment 7. This experiment concluded that an awareness of the presence and proximity of others in reality should be linked to user engagement with reality. Being fully engaged with a user would render them in VR in the same virtual position as in reality, relative to the VR HMD wearer. However, whilst this approach was disruptive to the immersion in VR, and failed to establish a low-engagement state for communicating presence and proximity, it did provide the basis for future investigations into how presence and proximity could be communicated in a low-engagement manner.

Overall, this thesis concludes that VR HMDs should provide a capability for the wearer to be aware of, and engage with, others in the same room in reality. Using room-wide sensing to render those in reality in VR, in the same virtual position as in reality relative to the VR HMD wearer, sufficiently communicates both who is there, and where they are relative to the VR HMD wearer. However, this thesis affirms that, based on the definition of Engagement-Dependent Augmented Virtuality, lower-engagement states for communicating presence are required.

9.2.5.1 LIMITATIONS AND FUTURE WORK

Future work would be required to evaluate the qualitative findings of Experiment 7, regarding the elicited ways in which a low-engagement state could be conveyed for proximate persons, for example through abstract visuals (e.g. changing the environment in some way ambient way, or through overt notifications) or non-visual modalities (e.g. vibro-tactile feedback, audio etc.). If the user is unaware that someone has entered the room then they cannot know to increase their engagement with reality. Allowing elements of reality to elevate to an engaged state with the user is a sensible approach and comparable to notifications in other interaction scenarios. In this way, users could be provided with sufficient awareness to be able to know who is in the same space, such that they could choose to engage with them if they so wished, whilst proximate persons could also initiate interactions with VR users. Such techniques may even be used to improve awareness in the high-engagement state, for example dealing with situations where the VR user has not yet looked in the direction of a proximate person. Future research will also be required to examine how engagement can be defined and measured in such scenarios.

9.2.6 RESEARCH QUESTION 6

How are VR HMDs likely to change the nature of synchronous media consumption at-a-distance?

Research Question 6 was answered in Chapter 8, *At-A-Distance Media Consumption Using VR HMDs*. By contrasting TV viewed together, TV at-a-distance, and VR at-a-distance across various levels of immersion, Experiment 8 answered this question by finding that mixed reality rendering of users in a shared space was significantly preferred to TV at-a-distance, and was broadly comparable to TV together. In essence, VR HMDs allowed for a semblance of being together in a shared space, in contrast to the Picture-in-Picture video mediated communications of TV at-a-distance. Engaging in more immersive experiences, in the form of a VR Cinema, and VR 360° experiences, reinforced this preference. However, the greater effort required to consume 360° media may prove to be an impediment to its adoption for longer duration viewing that will require future work to further establish and mitigate against.

Overall, this thesis concludes that it is highly likely that VR HMDs will change the nature of synchronous media consumption at-a-distance, given their capability for more immersive experiences, and mixed reality embodied communications, both of which were preferred by users over Picture-in-Picture TV at-a-distance as previously examined in literature.

9.2.6.1 LIMITATIONS AND FUTURE WORK

This research has identified a number of areas of further research regarding the consumption of 360° experiences. Firstly, in terms of the physical workload of viewing, the amount of effort expended by participants in viewing 360° content was significantly greater than viewing a single-focus TV / Cinema activity, and could present a barrier to consuming this media in durations approaching typical TV and film content. This effort could be reduced through a number of ways: the rendering or creation of VR content which helps manage both user attention, and what is available to attend to; alleviating fears of missing events in 360° content, fears which in turn fuel more viewing; providing an interactive non-physical means of managing viewing; or even through physical manipulations of the VR user [78]. Secondly, room-wide, multi-angle sensing will be required to render users from their partner's perspective in a fidelity that goes beyond the existing use of avatars (as seen in implementations of at-a-distance Cinema scenarios such as Oculus Social Alpha) and thus provide experiences comparable to those created in a lab setting.

Thirdly, increasing connectedness with others in the experience is also likely worthwhile – by knowing you are attending to the same area as your partner (e.g. by conveying the action point as discussed in [14], by facilitating mutual orientation [93], or perhaps by physically actuating orientation [78]) togetherness may be fostered through a shared focus of attention, and prior concerns regarding missing events perhaps alleviated further still. This overlaps with the issue of occlusion: in wearing VR HMDs, our ability to express ourselves to others is diminished, with facial expressions and eye gaze in particular curtailed. Finding ways to capture and convey the VR HMD user's engagement, emotional investment (e.g. through facial expressions [121]), and physical attention (such as in the case of ImmerseBoard [92] where gaze, gesture direction and intention are all conveyed to a remote partner) might help to reinforce togetherness in such experiences. Finally, there is a wider application of the techniques used here to collocated interactions e.g. being able to share a VR experience with multiple collocated VR HMD users.

9.2.7 General Limitations

In all the Experiments contained in this thesis, the choice of experimental task was made on the basis of ecological validity, prior use in the reviewed literature, and suitability to the prototype system being evaluated. For example, collaborative holiday planning, movie browsing, and EPG browsing were all used in the collocated TV experiments. Whilst the task chosen may have had an effect on the results for any given study, and thus in what contexts each system might prove most useful, it is important to note that these tasks had high ecological validity, whilst the experiments themselves had high internal validity, and it would be for future, follow-up research to re-examine these systems and designs across other tasks.

The majority of Experiments in this thesis were conducted in laboratory settings that were made to appear as close to the requisite real-world setting as possible, typically a home living room. This is aside from Experiment 6, which was conducted in week-long deployments in-the-wild. In addition, ecological validity was prioritized through the task designs, and the applications used (e.g. relying on real-world Android and Chromecast applications in use by consumers). Given that these experiments were conducted in unfamiliar laboratory settings, for durations typically under 2 hours of use, the external validity of these results is also a concern. However, the practicalities of in-the-wild deployments for the prototypes developed in this thesis precluded such evaluations. For example, the multi-view display prototypes all relied upon active shutter glasses and a 120 Hz 3D display, due to the unavailability of glasses free 3D TVs. Such a prototype was neither suitable for long-term use (given the reliance on active shutter glasses leading to fatigue) nor real world deployment (supporting only two users at a time, with no integration of existing TV content such as satellite and cable boxes). In addition these prototypes were not integrated into existing consumer TV content delivery systems to be deployed into homes e.g. being unable to co-exist or display the content of a cable or satellite box. Again, it would be for future research to re-examine these systems and designs at such a time that these technologies can be deployed into homes. It is important to note that, where possible, real-world deployments were used e.g. in the evaluation of the CastAway system.

9.3 GENERAL DISCUSSION

The findings from this thesis can broadly be distilled into two overarching discussions, firstly considering the roles of awareness and engagement in designing collocated TV and VR displays, and secondly in considering the future of synchronous at-a-distance media experiences given the possibility of TV at-a-distance compared to VR with embodied telepresence at-a-distance.

9.3.1 THE ROLES OF AWARENESS AND ENGAGEMENT IN COLLOCATED TV AND VR DISPLAYS

The literature review of this thesis began by examining the role of technology in aiding collaboration and supporting various forms of awareness in small groups, and each subsequent chapter has built upon this understanding. Chapter 3 started off by examining how collaboration and cooperation could be facilitated through interaction design, with multiple users interacting through a single shared interface. In considering Gutwin and Greenberg's definition of "workspace awareness" [80], the system evaluated in this Chapter allowed users to maintain a constant awareness of who was interacting, what they were doing, and what they could see, as all users were attending to, and interacting with, a single shared TV and a single shared interface. However, this approach was recognised as restrictive, with users being tightly coupled and unable to operate independently. This is what fundamentally drives the adoption of multi-screening: users transition to other devices in order to perform independent and private actions.

Consequently, Chapters 4 and 5 examined what role the TV could play in terms of supporting collaboration whilst allowing for the possibility of independent activity, with the aim being that users would have control over what they wished to attend to i.e. applying a conceptualization of engagement [175] to awareness of other's activities. In this way, users could instead determine how loosely or tightly coupled they were to those they were collaborating with. From making multi-screen activity more shareable and accessible through the shared focal point of the TV, to providing users with the capability to dynamically vary their engagement with other's activities on a multi-view display, this thesis exemplified that giving users control over the "what" of workspace awareness ("what are they doing" / "what goal is that action part of?" / "What object are they working on?") resulted in collocated TVs that better facilitated independent and shared use. Evaluation of these prototypes emphasized that users should be able to dictate and control their awareness of, and engagement with, others in both single and multi-display groupware in the home. Through this, groups could vary their entitativity dynamically on the basis of the needs of the collaborative task, going from high entitativity when attending to each other's activities, to low entitativity when operating independently, in a way that was not possible in Chapter 3. This activity might originate on multi-screen devices, or a smart TV, but the principle remains the same: facilitating dynamic awareness based on user engagement, with the TV being the large, gaze-accessible portal through which this awareness is provided.

This principle of dynamic awareness based on engagement was then applied to collocated VR HMD use and formalized in Chapter 7. Here, awareness was provided of proximate collocated persons i.e. those in the same room as the VR HMD user. In TVs, varying awareness based on user engagement minimized distraction and facilitated independence. Similarly, with VR HMDs varying awareness based on user engagement helped to preserve presence in VR by minimizing the extent to which virtuality was augmented with reality in order to convey this presence of proximate persons. What these chapters emphasize is that technology which imparts awareness should take into account the need for this awareness to vary based on user engagement.

9.3.2 THE FUTURE OF SYNCHRONOUS AT-A-DISTANCE MEDIA CONSUMPTION

Chapters 6 and 8 offer two alternate points of view regarding at-a-distance media consumption that are fundamentally complementary i.e. it is not necessarily the case of one superseding or replacing the other over a given time frame. With respect to how synchronous at-a-distance experiences are conducted in the future, in the short term the implementation of TV at-a-distance in Chapter 6 offers an accessible means of engaging in shared activity. It utilizes existing, highly-prevalent displays (in the form of the TVs and smartphones) and can be facilitated at very little cost (as demonstrated by the implementation of CastAway using $30 Chromecast dongles). CastAway sessions could be started with one button press from each participant, meaning there was a low barrier of entry. Moreover, there already exists an ecosystem of applications and content which could be conveyed and shared in this manner (e.g. any application with "cast" support). CastAway also supported varying user engagement, both in terms of attention to the content being consumed (e.g. primarily attending to another activity, in the case of Music, versus focussing entirely on the shared content, in the case of TV content), and in terms of the on-going communication (for example with participants in Study 1 escalating to higher fidelity/bandwidth of communication VMC for media selections, and lower fidelity textual communications during consumption, allowing participants to manage the attentional demand of the communication).

In contrast, whilst VR at-a-distance might provide the most embodied form of communication and consumption at-a-distance, it is implicitly heavyweight by design. It involves the consumption of immersive content which predominantly precludes attending to any other activities (although this is dependent on the design of the VR experience). And it requires that extraneous capture equipment be available (to track and convey the VR user) and the wearing of a headset which predominantly shuts off reality.

Over a long enough timespan, these two approaches are likely to converge. For example, if the "TV" is rendered by an AR headset such as Microsoft Hololens, then companions at-a-distance could be rendered in much the same way, allowing their presence to be seamlessly inserted into your real-world environment. Similarly, if said AR headset can selectively occlude reality, users could seamlessly transition from experiences rooted in reality, to immersive virtual environments, and incorporate those at-a-distance into these experiences in the process. However, what this research emphasizes is that the context of consumption will play a large role in determining the modality of communication. This context can vary in a number of ways e.g. the existing social context of the real-world space, the fidelity and required engagement of communication, the required engagement and immersion of the medium by which the content is being consumed, preferences regarding the content being consumed, whether there are other ongoing activities to be attended to and so on. In essence, the highest fidelity mode of communication (e.g. VMC in Experiment 6, embodied telepresence VR in Experiment 8) is not necessarily the optimal choice for any given confluence of these factors. Chapter 6 showed that users need to have sufficient control over how communication is handled, based on their personal engagement with the at-a-distance experience, but Chapter 8 demonstrated that embodied experiences have the potential to go significantly beyond traditional VMC approaches, where the context of consumption allows for their usage.

What this demonstrates is that there is no absolute, prescribed means by which at-a-distance media consumption should occur. Instead, users should be given sufficient flexibility to adapt their at-a-distance experiences to meet the constraints of their personal context. The content being consumed can vary from total immersion, to being a secondary activity on a TV or other display, to being a shared audio space where no visual attention is required. The communication modalities employed can range from fully embodied high-engagement telepresence, to lower-engagement textual communication, and will vary individually on the basis of what is acceptable in a given personal and social context.

In effect, the only required commonalities for a couple to share an experience together at-a-distance are that communication be facilitated in some way, and that some media form or experience be synchronously conveyed to both people, and technology should aim to reduce the barriers to achieving this. For example, if a VR user in an immersive environment wishes to share some part of this experience with a partner at-a-distance, they should be able to do so, with each partner viewing and communicating through whatever means best suits their particular context. Similarly, even listening to music in the kitchen could be turned into a shared and synchronous experience, and provide a feeling of connectedness between those that are geographically separated. However, for these possibilities to come about, this requires a will to design for, and support, synchronous at-a-distance experiences in media playback platforms. Moreover, this will require further research to examine how best to bring users together in these experiences, how best to facilitate communication across these contexts, and how to make users aware of the serendipitous possibilities for turning personal, private experiences into shared at-a-distance experiences with those they share personal connections with.

9.4 FINAL REMARKS

This thesis was motivated by the future role that TVs and VR HMDs could play in both collocated and at-a-distance media consumption. In each case, this thesis has resulted in the creation and evaluation of new systems, and shown novel results, demonstrating the potential of both TV and VR HMDs and guiding future work in this area.

For collocated use, the TV offers a unique shared focal point for those that cohabitate, and is the means by which viewers most immersively consume media, with TV experiences enhanced by viewing together. This thesis explored how the TV could better fit the shared, social context in which it often resides, supporting multi-user interaction whilst retaining existing interfaces, enabling multi-user use, and providing awareness of the multi-screen activity of those in the room. Through mediation of control, an existing TV interface can be shared by virtualizing who is in control. Multi-view display technology enables truly multi-user use of the TV, with shared, collaborative and independent use possible without disrupting others' experiences. Moreover, multi-view TVs diminish reliance upon the closed off, heads-down smartphone / tablet use that is currently commonplace. When users do engage in multi-screening, this activity can be made accessible to those in the same room through the shared focal point of the TV, through active and passive screen mirroring.

For at-a-distance use of the TV, this thesis demonstrated novel results showing that at-a-distance experiences could be facilitated right now, using an existing consumer smart TV platform. Secondly, this thesis elicited a new understanding as to what media types can play a role in at-a-distance consumption, how couples chose to communicate during synchronous and shared media experiences, and the beneficial effect at-a-distance media consumption has on couples in long distance relationships.

In time, VR HMDs will supplement, and may even supplant, the TV for a variety of roles, due to the level of immersion and 360° workspace they provide in a virtual experience. Accordingly, this thesis explored the usability impediments to the use of VR HMDs for the first time, finding that communicating the presence and proximity of others in the real world was a necessary step to providing usable VR experiences, before then examining how this presence and proximity could be communicated in collocated settings.

For at-a-distance use of VR HMDs, this thesis has demonstrated novel results showing that VR HMDs are significantly better suited to at-a-distance media consumption than TVs, with those at-a-distance able to share a virtual space as if together once more. Furthermore, this thesis suggests that users consuming 360° media with others in VR will require additional support, in order to both combat the fatigue of viewing, and the lack of a shared focal point.

Fundamentally, this thesis emphasizes the need for consumer display technologies to take into account others, be they those in the same room, or at-a-distance. From productivity and collaboration, to entertainment, to simply being together once more for the duration of a film, TVs and VR HMDs can play a significant role in the home, and are capable of much more than they are currently used for.

A. Statistics and Plots

There has been some debate within the HCI community[1] regarding the traditional use of Null Hypothesis Significance Testing (NHST) being a flawed approach[2]. For example it has been put forward that NHST should be banned in favour of estimation [51] e.g. reporting confidence intervals and clear visualizations. However NHST is still widely expected in HCI publications, and thus this thesis (and the publications it is based on) use NHST.

Accordingly, this thesis takes care to both follow best practices regarding NHST, whilst beginning to transition to estimation / visualization. Firstly, the choice of parametric versus non-parametric NHST is made on the basis of the type of data being used (see Section A.1.1). Secondly, parametric tests are conducted using multilevel modelling (see Section A.1.2.2), meaning the testing conducted is robust against homogenity / normality violations, thus avoiding unnecessary use of non-parametric tests or data transformations. Thirdly, where plots are rendered they are typically violin plots combined with notched box plots that indicate 95% confidence intervals, thus allowing for estimation of the results through visualization.

A.1 Statistical Tests

A.1.1 Parametric vs Non-Parametric Tests

In order for parametric tests to be used, typically data must [57]:

1. Be normally distributed – in sampling distribution or the errors in the model, looking at skew, kurtosis (peaked versus flat data), or normality tests such as the Anderson-Darling or Shapiro-Wilk tests

[1] http://www.aviz.fr/badstats
[2] e.g. http://lesswrong.com/lw/g13/against_nhst/

2. Not violate homogenity of variance / sphericity (variances of differences between all combinations of levels should be the same throughout the data)
3. Be measured at least at the interval level
4. Satisfy independence (the behaviour of one participant does not influence the behaviour of another)

Violations of these assumptions would cause an increase in Type I (incorrect rejection of a true null hypothesis i.e. a false positive, see Section A.1.3) and / or Type II (failure to reject a false null hypothesis i.e. a false negative, see Section A.1.4) errors. If the distribution of the data / sampling population violate these criteria, then there are three possibilities [134]:

1. Proceed with the parametric test
2. Transform or clean the data to correct the violations, then proceed with the parametric test
3. Use a non-parametric test

There are reasons and caveats for following each of these approaches, as discussed in [134] which will be summarized here. Proceeding with parametric tests is a common approach, on the basis that parametric tests are “reasonably robust to violations and, in any event, the underlying assumptions are rarely met when analyzing real data” and that “even with small sample sizes... the consequences of violations in the assumptions underpinning the ANOVA are usually minor” (from [134] summarizing [54]). This robustness has been demonstrated in literature [188]. As Dragicevic [51] states:

> “The world is not sharply divided into normal and non-normal distributions. This false dichotomy has been largely promoted by normality testing procedures, which violate the unconditionality principle and are both logically and practically unsound (Wierdsma, 2013; Stewart-Oaten, 1995, p.2002).”

Transforming data in order to correct for violations of normalcy and allow parametric testing has in recent years typically been accomplished using aligned rank transforms for non-parametric analysis using ANOVAs [232], however such approaches lose statistical power. Moreover there is some debate as to the role of transformations and the effect they have on results, with Sheskin suggesting that “one might view a data transformation as little more than a convenient mechanism for ‘cooking’ data until it allows a researcher to achieve a specific goal” [193]. Proceeding with a non-parametric test means the data is also collapsed into ranks. This can be problematic as “when a researcher elects to transform a set of interval/ratio data into ranks, information is sacrificed” [193]. MacKenzie [134] states that “choosing a non-parametric test for ratio-scale measurements that deviate from normality is to replace one deficiency with another", adding that "restraint is advised". In addition, MacKenzie suggests that the question being asked should not necessarily be "are the assumptions of the parametric ANOVA met?" but instead "what are the consequences of the inevitable violations in the parametric ANOVA?".

Mackenzie determined that in choosing between parametric and non-parametric tests for ratio/interval data "arguably, the balance tips in favor of parametric tests due to the added precision and statistical power". As such, this thesis uses parametric tests for ratio / interval data, and non-parametric tests for ordinal data (e.g. Likert type scales), with no normality tests reported. The exception to this is where a factorial n–way test is required for non-parametric data, where an aligned-rank transform is used to allow for parametric testing (e.g. two / three-way ANOVA).

A.1.2 TESTS USED

A.1.2.1 OVERVIEW OF NULL HYPOTHESIS SIGNIFICANCE TESTING

This thesis relies on Null Hypothesis Significance Testing (NHST) throughout. In NHST, a statistical hypothesis is first developed, referred to as the null hypothesis (H0). For example the null hypothesis could state that the mean of the dependent variable is the same for all groups. Given this, the alternate hypothesis is proposed, in this case that the mean of the dependent variable is not the same for all groups. Kirk [112] described NHST in the following terms:

> "In scientific inference, what we want to know is the probability that the null hypothesis (H0) is true given that we have obtained a set of data (D); that is, p(H0|D). What null hypothesis significance testing tells us is the probability of obtaining these data or more extreme data if the null hypothesis is true, p(D|H0)." [112] from [65]

The NHST being used produces a test statistic which in turn is used to calculate a p-value. The p-value is the probability of obtaining an effect at least as extreme as what was observed, when the null hypothesis is true, meaning that, for example, if the p-value of a test is 0.05 then there is a probability of 0.05 that the null hypothesis will be mistakenly rejected. The p-value is interpreted through use of a threshold value, the significance level of the test, which is traditionally either 5% or 1% (this thesis uses 5%, meaning a p-value of 0.05, throughout). If the p-value is less than or equal to the chosen significance level, then the test suggests that the sample is inconsistent with the null hypothesis, and thus it provides strong evidence that the null hypothesis should be rejected in favour of the alternate hypothesis.

Over the course of this thesis, three types of significance test were used for showing an overall significant difference in group means: repeated measures ANOVA (a parametric test, with an aligned-rank transform used if being conducted on non-parametric data), factorial repeated measures ANOVA and Friedman's ANOVA. These tests all state the null hypothesis as the mean of the dependent variable being the same for all groups. If the test was significant, *post-hoc* tests were used to confirm where the differences between groups occurred. How these tests were conducted and reported, and which *post-hoc* tests were used is now discussed in turn.

A.1.2.2 PARAMETRIC TESTS

ALIGNED-RANK TRANSFORM In cases where it is necessary to perform a parametric test on non-parametric data, an Aligned-Rank Transform (ART) [232] was used:

> "The ART relies on a preprocessing step that 'aligns' data before applying averaged ranks, after which point common ANOVA procedures can be used."

This is used in cases where a factorial ANOVA needs to be performed, or where a specific post-hoc test is required (e.g. Experiment 1 using Dunnet's Test for comparing against the control).

REPEATED MEASURES ANOVA For within-subjects experiments with parametric data, a repeated measures ANOVA was performed. The method employed used a multilevel linear model as described in Chapter 13 of [57]. Because of the usage of *lme()*, sphericity is not an issue (as the variance is explicitly modeled), whilst the assumption of normality changes to assume that the residuals of the model are normally distributed[3], examined using *qqnorm()*. *F* statistics (ratio of two mean square values) are not reported. Instead, reporting takes the form of:

$$\chi^2(dof) = L.Ratio, p = Significance \tag{A.1}$$

Where dof is the degrees of freedom between the baseline model and the model tested, $L.Ratio$ is the likelihood ratio which describes whether this improvement in fit is significant, in terms of how many times more likely the data is under one model versus the other, and p is the probability of the effect being observed if the null hypothesis is true, computed on the basis of the likelihood ratio.

[3] http://stats.stackexchange.com/questions/77891/checking-assumptions-lmer-lme-mixed-models-in-r

POST HOC TESTS Depending on the study, either *post hoc* Tukey contrasts / HSD (pairwise comparisons) or a *post hoc* Dunnet's test (comparing each Condition with the Control) were performed, both using *glht()*. No adjustment was performed as both tests are protected against Type I error (familywise errors, i.e. false positives) using multilevel models [63].

FACTORIAL REPEATED MEASURES ANOVA Factorial RM-ANOVAs are also calculated using *lme()*. The statistical significance of effects on each factor, and interaction effects, are reported, and in the case(s) where there is an effect, contrasts are performed as described in [57] using *glht()*. Reporting for these takes the form of:

$$F(numDF, denDF) = F.value, p = Significance \tag{A.2}$$

Where $numDF$ is the numerator degrees of freedom ("the number of degrees of freedom that the estimate of variance used in the numerator is based on") and $denDF$ is the denominator degrees of freedom ("The dfd is the number of degrees of freedom that the estimate used in the denominator is based on")[4]. $F.value$ is the F statistic, calculated by the explained variance or between-group variability divided by the unexplained variance or within-group variability (so as this increases it indicates that the between-group variation is greater than the within-group variation), and p is the probability of the effect being observed if the null hypothesis is true.

A.1.2.3 NON-PARAMETRIC TESTS

FRIEDMAN'S ANOVA For within-subjects experiments with non-parametric data, a Friedman's ANOVA was performed (*friedman.test()*). This is reported as:

$$\chi^2(dof) = Fit, p = Significance \tag{A.3}$$

where dof is the degrees of freedom ($numberofrepeatedmeasures - 1$) and Fit is the goodness of fit to a χ^2 probability distribution with dof degrees of freedom in order to calculate the p-value.

Post Hoc TESTS For *post hoc* tests, a Pairwise Wilcoxon Rank Sum Test was used (*pairwise.wilcox.test(... paired=T)*), with Bonferroni correction to account for the number of hypotheses being tested (which leads to an increase of Type I errors).

[4] http://davidmlane.com/hyperstat/A107688.html

A.1.3 TYPE I ERRORS (FALSE POSITIVES)

The incidence of Type I errors (null hypothesis being true and rejecting it) was guarded against in *post hoc* multiple comparisons for non-parametric tests through the use of Bonferroni correction, and for parametric tests by use of tests that were protected against Type I error.

A.1.4 TYPE II ERRORS (FALSE NEGATIVES)

The incidence of Type II errors (null hypothesis being false and failing to reject it) was guarded against by matching or exceeding guidelines where possible regarding sample sizes in HCI usability evaluations by Hwang and Salvendy [101], who suggested that 10 ± 2 was sufficient for eliciting 80% of usability concerns and ensuring sufficient statistical power.

A.2 PLOTS

A.2.1 VIOLIN PLOTS

Plots in this thesis predominantly combine violin plots with box plots as pioneered by Hintze *et al* [94]. Violin plots were conceived because:

> It adds the information available from local density estimates to the basic summary statistics inherent in box plots. This marriage of summary statistics and density shape into a single plot provides a useful tool for data analysis and exploration.

Violin plots are plotted using *geom_violin()*[5] displaying a rotated kernel density plot on either side of a box plot. This kernel density plot is a non-parametric estimate of the probability density function of a continuous random variable which describes, when taking the integral of an interval, the probability of the variable falling within said interval. Thus, the thicker the plot at a particular point, the denser that particular region, whilst long thin plots describe wide distributions of data.

Boxplots are plotted via *geom_boxplot()* with the boxes indicating the first and third quartiles (interquartile range, the 25th and 75th percentiles) and the whiskers extending to the highest/lowest value that is within 1.5 * the interquartile range of the box (distance between 25th

[5] http://docs.ggplot2.org/current/geom_violin.html

and 75th percentiles). Data beyond these bounds are plotted as outlier points (as specified by Tukey).

The notches (diagonal lines within the boxplot) display the 95% confidence interval ($1.58 * interquartilerange/sqrt(n)$). Although not a formal test, "if two boxes' notches do not overlap there is 'strong evidence' (95% confidence) that the medians differ"[6]. If the notches extend beyond the body of the boxplot, this means that the confidence interval is greater than the interquartile range. In all cases, SD refers to Standard Deviation.

A.2.2 KERNEL DENSITY PLOTS

Kernel density plots are plotted using *stat_density*[7] with the default gaussian kernel. This function calculates the optimal smoothing bandwidth / bin size for the plot, and any kernel density plots that apply a multiplier to this value report this multiplier in the plot.

A.3 GINI COEFFICIENTS

These are a measure of inequality used for analysing viewing distribution in previous studies e.g. [226]; 1 denotes maximum inequality i.e. $100 - 0$ or $0 - 100$, and 0 maximum equality i.e. a 50-50 distribution when dealing with two items. The function used for calculating the Gini coefficient is supplied by the *ineq* package in R, and is as follows:

```
function (x, corr = FALSE, na.rm = TRUE)
{
    if (!na.rm && any(is.na(x)))
        return(NA_real_)
    x <- as.numeric(na.omit(x))
    n <- length(x)
    x <- sort(x)
    G <- sum(x * 1L:n)
    G <- 2 * G/sum(x) - (n + 1L)
    if (corr)
        G/(n - 1L)
    else G/n
}
<environment: namespace:ineq>

#(corr was set to TRUE for all calls as corr corrects for bias in
    small sample sizes)
```

[6]https://sites.google.com/site/davidsstatistics/home/notched-box-plots
[7]http://docs.ggplot2.org/0.9.3.1/stat_density.html

Gini coefficients are typically used in this chapter for illustrating the extent to which viewing was distributed between available displays or devices. As an example, consider 3 people viewing 3 devices over a 100 second period. If they were each heavily viewing their own device, but only occasionally glancing at their partners devices, a representative distribution might be:

Person	Device 1	Device 2	Device 3
P1	80 secs	15 secs	5 secs
P2	10 secs	80 secs	10 secs
P3	3 secs	12 secs	85 secs

The result of this would be that the Gini coefficient of each person would be skewed toward inequality (1), as follows:

Person	Device 1	Device 2	Device 3	Gini Coefficient
P1	80 secs	15 secs	5 secs	0.75
P2	10 secs	80 secs	10 secs	0.7
P3	3 secs	12 secs	85 secs	0.82

If viewing were more evenly distributed, then the Gini coefficient becomes skewed toward equality (0):

Person	Device 1	Device 2	Device 3	Gini Coefficient
P1	30 secs	35 secs	35 secs	0.05
P2	25 secs	40 secs	35 secs	0.15
P3	33 secs	30 secs	37 secs	0.07

In this way, the Gini coefficient is a measure of the equality of distribution amongst a population.

A.3.1 DIRECTED GINI COEFFICIENT FOR EQUALITY BETWEEN TWO POINTS

When used with two comparison points, the Gini coefficient effectively becomes a measure of the distance between two points normalized to between 0 (equality) and 1 (inequality):

$$abs(P1 - P2)/(P1 + P2) \tag{A.4}$$

So for a ratio of $2:1$ the Gini coefficient would be 0.33, whilst $5:1$ would be 0.66 $(5-1/5+1)$. However, this removes directionality from the result. For example, viewing device 1 for 90 seconds and device 2 for 10 seconds, and viewing device 1 for 10 seconds and device 2 for 90 seconds both equate to the same Gini coefficient (0.8). Where applicable this thesis encodes the direction of equality, such that $100 : 0$ would resolve to 1, and $0 : 100$ would resolve to -1. In this way, the Gini coefficient reflects both the distribution of viewing in our example, but also whether viewing was biased toward device 1 or device 2. In the example, if the viewing was biased toward device 1, the Gini coefficient would be negated. Thus if viewing device 1 for 90 seconds, and device 2 for 10 seconds, the Gini coefficient would be -0.8, while viewing device 1 for 10 seconds and device 2 for 90 seconds would be 0.8. In this way, the Gini coefficient effectively becomes a measure of the distance between two points normalized to between -1 and 1, where 0 is equality, and -1 and 1 are complete inequality toward either device 1 or device 2.

B. Supplemental Materials

Questionnaires, question sets and surveys can be found in the appendices that follow this one.

For supplemental materials (PDF copies of contributing publications, experimental data) please contact me at mmcgill@gmail.com or look at www.markmcgill.co.uk for more details.

C. Existing TV Consumption Behaviours Survey

The following questions constituted the questionnaire from Chapter 3 regarding existing TV consumption behaviours, as well as an overview of the results.

About the Media Consumption Survey

You are being invited to take part in an online questionnaire, which **should take approximately 10-12 minutes to complete**. Before you continue, please take time to read the following information carefully. If there is anything that is unclear, or you would like more information, please feel free to contact us, at the email addresses listed below.

Participation is optional, and the questionnaire can be exited at any time. You must be aged 18 or over to take part.

Researcher (PhD Student): Mark McGill m.mcgill.1@research.gla.ac.uk

Supervisor: Professor Stephen Brewster Stephen.Brewster@glasgow.ac.uk

What is the purpose of this study?

The purpose of this study is to gain an insight into the media consumption habits (e.g. watching a film, or playing a video game) of people in different social settings (e.g. with friends, family, etc.), their reactions to issues encountered in these settings, the kinds of devices that might be used, and the types of personalities involved.

What will happen if i take part?

You will be asked to answer a series of optional questions, predominantly multiple choice, with some optional written statements, lasting approximately 10-12 minutes in total.

All information will be stored securely and kept anonymous. There is a completely optional question asking for your name and email address, if you wish to be notified of further studies in this area, but this information will be kept confidential and will be used only for contact purposes in the event of future research.

The results of this study may end up being used in research publications, and possibly a doctoral thesis, but again with emphasis that all results will be anonymized. By hitting the "next" button you give your consent for the data you provide to be used, as described above.

This project is part of a industrial studentship PhD being conducted at the University of Glasgow.

*1. What is your age?

- 18 to 24
- 25 to 34
- 35 to 44
- 45 to 54
- 55 to 64
- 65 to 74
- 75 or older

2. What is your gender?

- Female
- Male

3. What do you study/what field do you work in?

4. What is your living status?

- [ ] Alone
- [ ] With Partner
- [ ] With Parents
- [ ] With Children
- [ ] With Flatmates

Other (please specify)

Devices (cont)

5. Which of these control methods do you use to control your TV/set top box/media systems in your household?

	Daily	Weekly	Rarely	Never/Do not own
Remote control (per device)	◯	◯	◯	◯
Universal remote	◯	◯	◯	◯
Physical controls on device	◯	◯	◯	◯
Smartphone/tablet apps	◯	◯	◯	◯
Web-based interface	◯	◯	◯	◯
Gesture interface (e.g. Kinect, Samsung SmartTV, wand)	◯	◯	◯	◯
Voice control (e.g. Siri, Google Voice Search)	◯	◯	◯	◯
Keyboard/Mouse	◯	◯	◯	◯
Ask someone to do it for you	◯	◯	◯	◯

Other (please specify)

Devices (cont)

6. Of the following devices, which are you likely to have on your person, and how frequently?

	On my person at all times	Daily	Weekly	Rarely	Not at all/Do not own
Tablet	◯	◯	◯	◯	◯
Smartphone	◯	◯	◯	◯	◯
Laptop	◯	◯	◯	◯	◯
e-book reader	◯	◯	◯	◯	◯
MP3/Media player	◯	◯	◯	◯	◯
Portable games console	◯	◯	◯	◯	◯
Bluetooth headset	◯	◯	◯	◯	◯

7. In your experience, how are decisions most often made within the following groups, regarding choice of media (e.g. selection of a film, TV program, or game)?

	Individual(s) in charge	Voting	Debate amongst group	Predetermined ahead of time	Random selection	Turn taking	Other
Friends	☐	☐	☐	☐	☐	☐	☐
Family	☐	☐	☐	☐	☐	☐	☐
Colleagues / casual acquaintances	☐	☐	☐	☐	☐	☐	☐
Cohabitants	☐	☐	☐	☐	☐	☐	☐

Other (please specify)

8. How satisfied are you with the way decisions are made within the following groups, regarding choice of media to watch/consume (e.g. selection of a film, TV program, or game)?

	Very satisfied	Somewhat satisfied	Neither satisfied nor dissatisfied	Somewhat dissatisfied	Very dissatisfied
Friends	◯	◯	◯	◯	◯
Family	◯	◯	◯	◯	◯
Colleagues / casual acquaintances	◯	◯	◯	◯	◯
Cohabitants	◯	◯	◯	◯	◯

Comments regarding what you find satisfying/disatisfying about these decisions?

9. Describe how conflicts regarding choice of media to watch/consume are typically resolved, in your experience?

	Compromise *Find a solution that satisfies all parties*	Trade / Bargain *Do something unacceptable in return for something acceptable later*	Accommodation *Yield to others demands*	Competitive *Fight/argue in an attempt to win & have your preference selected*	Split *Group splits into subgroups to perform different activities*	Other *Please specify in the comments box below*
Friends	☐	☐	☐	☐	☐	☐
Family	☐	☐	☐	☐	☐	☐
Colleagues / casual acquaintances	☐	☐	☐	☐	☐	☐
Cohabitants	☐	☐	☐	☐	☐	☐

Comments regarding how conflicts tend to be resolved, in your experience

10. How is the control of media systems (e.g. TV, set top box) handled in your home? Is control determined based on...

	Happens all the time	Happens often	Happens on occasion	Happens Rarely	Never happens
..first come, first serve	◌	◌	◌	◌	◌
..passing control around	◌	◌	◌	◌	◌
..turn taking	◌	◌	◌	◌	◌
..hierarchical (individual(s) in charge)	◌	◌	◌	◌	◌
..taking control from whomever currently has it	◌	◌	◌	◌	◌
..scheduled blocks	◌	◌	◌	◌	◌
..negotiation	◌	◌	◌	◌	◌

Other (please specify)

11. How acceptable do you find the following ways of controlling media systems (e.g. tv, set top box)?

	Completely acceptable	Somewhat acceptable	Neither acceptable nor unacceptable	Somewhat unacceptable	Completely unacceptable
First come, first serve	◌	◌	◌	◌	◌
Passing control around	◌	◌	◌	◌	◌
Turn taking	◌	◌	◌	◌	◌
Hierarchical (individual(s) in charge)	◌	◌	◌	◌	◌
Taking control from whomever currently has it	◌	◌	◌	◌	◌
Scheduled blocks	◌	◌	◌	◌	◌
Negotiation	◌	◌	◌	◌	◌

12. How often do you perform the following on your own, but with others present, in a private setting like the home?

	Daily	Weekly	Rarely	Never
Watch Live/Broadcast TV	◯	◯	◯	◯
Watch Pre-recorded TV/Film	◯	◯	◯	◯
Listen to music	◯	◯	◯	◯
Listen to radio/spoken word	◯	◯	◯	◯
Play video games using physical controls	◯	◯	◯	◯
Play video games using gestural/motion controls	◯	◯	◯	◯
Play physical games	◯	◯	◯	◯
Browse web content	◯	◯	◯	◯
Browse personal content (e.g. holiday pictures)	◯	◯	◯	◯

13. How often do others perform the following in your presence, but without you joining in, in a private setting like the home?

	Daily	Weekly	Rarely	Never
Watch Live/Broadcast TV	○	○	○	○
Watch Pre-recorded TV/Film	○	○	○	○
Listen to music	○	○	○	○
Listen to radio/spoken word	○	○	○	○
Play video games using physical controls	○	○	○	○
Play video games using gestural/motion controls	○	○	○	○
Play physical games	○	○	○	○
Browse web content	○	○	○	○
Browse personal content (e.g. holiday pictures)	○	○	○	○

14. How often do you perform the following with friends, in a private setting like the home?

	Daily	Weekly	Rarely	Never
Watch Live/Broadcast TV	◯	◯	◯	◯
Watch Pre-recorded TV/Film	◯	◯	◯	◯
Listen to music	◯	◯	◯	◯
Listen to radio/spoken word	◯	◯	◯	◯
Play video games using physical controls	◯	◯	◯	◯
Play video games using gestural/motion controls	◯	◯	◯	◯
Play physical games (e.g. chess, twister etc.)	◯	◯	◯	◯
Browse web content	◯	◯	◯	◯
Browse personal content (e.g. holiday pictures)	◯	◯	◯	◯

15. How often do you perform the following with family, in a private setting like the home?

	Daily	Weekly	Rarely	Never
Watch Live/Broadcast TV	○	○	○	○
Watch Pre-recorded TV/Film	○	○	○	○
Listen to music	○	○	○	○
Listen to radio/spoken word	○	○	○	○
Play video games using physical controls	○	○	○	○
Play video games using gestural/motion controls	○	○	○	○
Play physical games (e.g. chess, twister etc.)	○	○	○	○
Browse web content	○	○	○	○
Browse personal content (e.g. holiday pictures)	○	○	○	○

16. How often do you perform the following with work colleagues or casual acquaintances, in a private setting like the home?

	Daily	Weekly	Rarely	Never
Watch Live/Broadcast TV	◯	◯	◯	◯
Watch Pre-recorded TV/Film	◯	◯	◯	◯
Listen to music	◯	◯	◯	◯
Listen to radio/spoken word	◯	◯	◯	◯
Play video games using physical controls	◯	◯	◯	◯
Play video games using gestural/motion controls	◯	◯	◯	◯
Play physical games (e.g. chess, twister etc.)	◯	◯	◯	◯
Browse web content	◯	◯	◯	◯
Browse personal content (e.g. holiday pictures)	◯	◯	◯	◯

17. How often do you perform the following with cohabitants, in a private setting like the home?

	Daily	Weekly	Rarely	Never
Watch Live/Broadcast TV	○	○	○	○
Watch Pre-recorded TV/Film	○	○	○	○
Listen to music	○	○	○	○
Listen to radio/spoken word	○	○	○	○
Play video games using physical controls	○	○	○	○
Play video games using gestural/motion controls	○	○	○	○
Play physical games (e.g. chess, twister etc.)	○	○	○	○
Browse web content	○	○	○	○
Browse personal content (e.g. holiday pictures)	○	○	○	○

18. Are there any other media consumption activities that you & your different social groups take part in, in private settings like the home, that haven't been mentioned thus far?

19. How well do the following statements describe your personality? "I see myself as someone who..."

	Agree strongly	Agree a little	Neither agree nor disagree	Disagree a little	Disagree strongly
...is reserved	○	○	○	○	○
...is generally trusting	○	○	○	○	○
...tends to be lazy	○	○	○	○	○
...is relaxed, handles stress well	○	○	○	○	○
...has few artistic interests	○	○	○	○	○
...is outgoing, sociable	○	○	○	○	○
...tends to find fault with others	○	○	○	○	○
...does a thorough job	○	○	○	○	○
...gets nervous easily	○	○	○	○	○
...has an active imagination	○	○	○	○	○

20. (Optional) Contact information. If you are interested in participating in our future research, please complete these fields.

Name:

Country:

Email Address:

21. Any additional comments or feedback?

Survey complete - Thanks!

The survey is now complete. If you have any questions or concerns about the survey, or you wish to receive a summary of the findings of this survey at a later date, please contact us at the email addresses below. **Thanks! Your completion of this survey is much appreciated!**

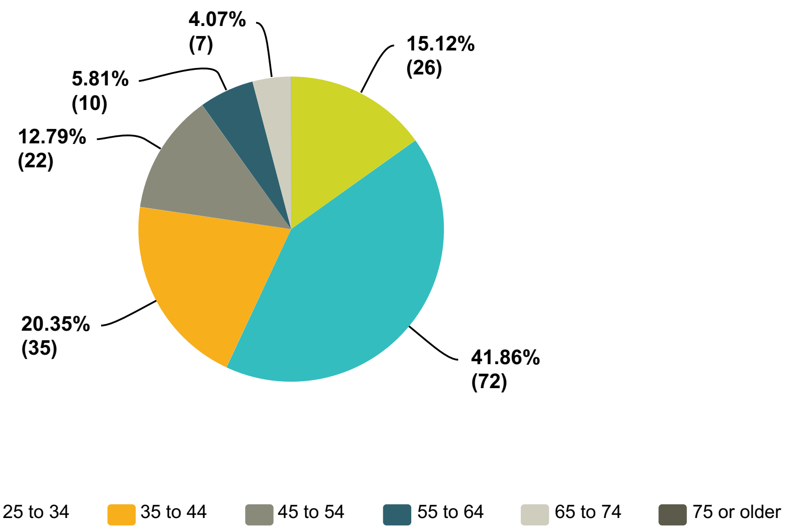
Researcher: Mark McGill m.mcgill.1@research.gla.ac.uk

Supervisor: Professor Stephen Brewster Stephen.Brewster@glasgow.ac.uk

This study adheres to the BPS ethical guidelines, and has been approved by the College of Science and Engineering ethics committee of The University of Glasgow (ref: CSE01140). Whilst you are free to discuss your participation in this study with the researcher, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee here.

Q1 What is your age?

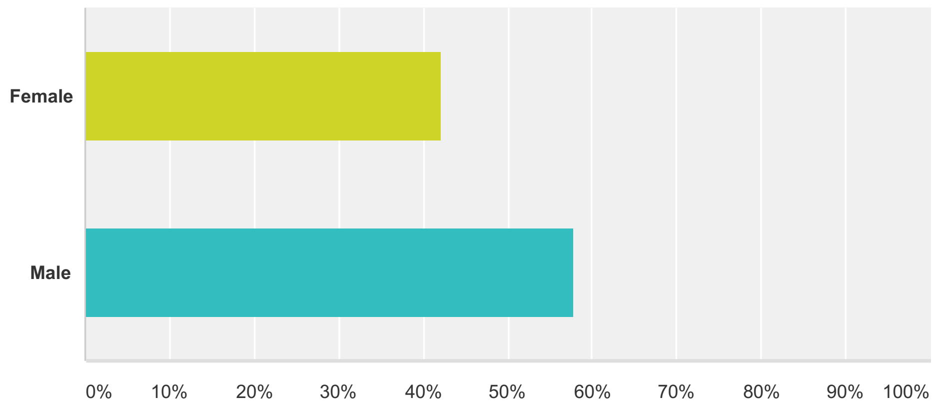
Answered: 172 Skipped: 0



Answer Choices	Responses	
18 to 24	15.12%	26
25 to 34	41.86%	72
35 to 44	20.35%	35
45 to 54	12.79%	22
55 to 64	5.81%	10
65 to 74	4.07%	7
75 or older	0.00%	0
Total		172

Q2 What is your gender?

Answered: 171 Skipped: 1



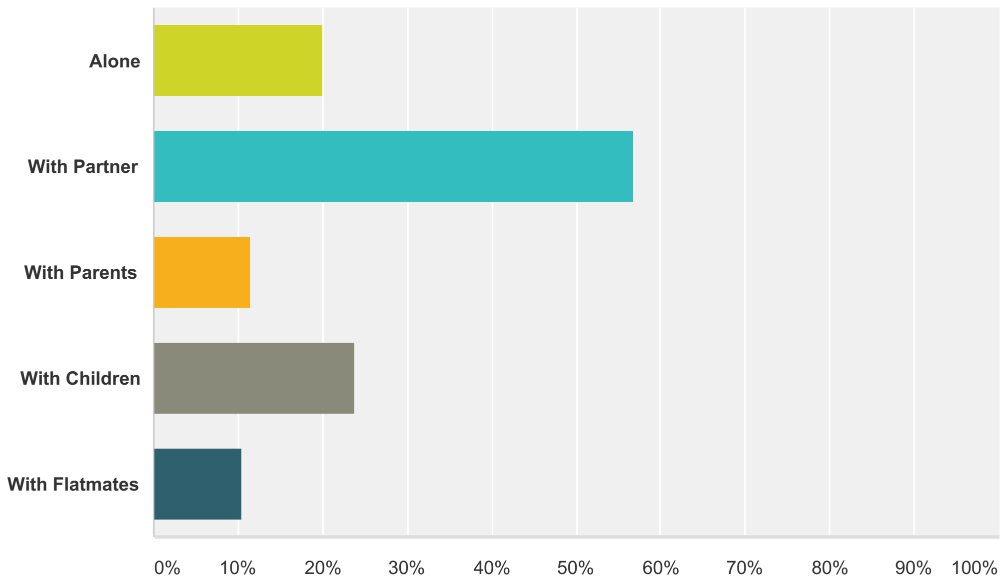
Answer Choices	Responses	
Female	**42.11%**	72
Male	**57.89%**	99
Total		**171**

Q3 What do you study/what field do you work in?

Answered: 157 Skipped: 15

Q4 What is your living status?

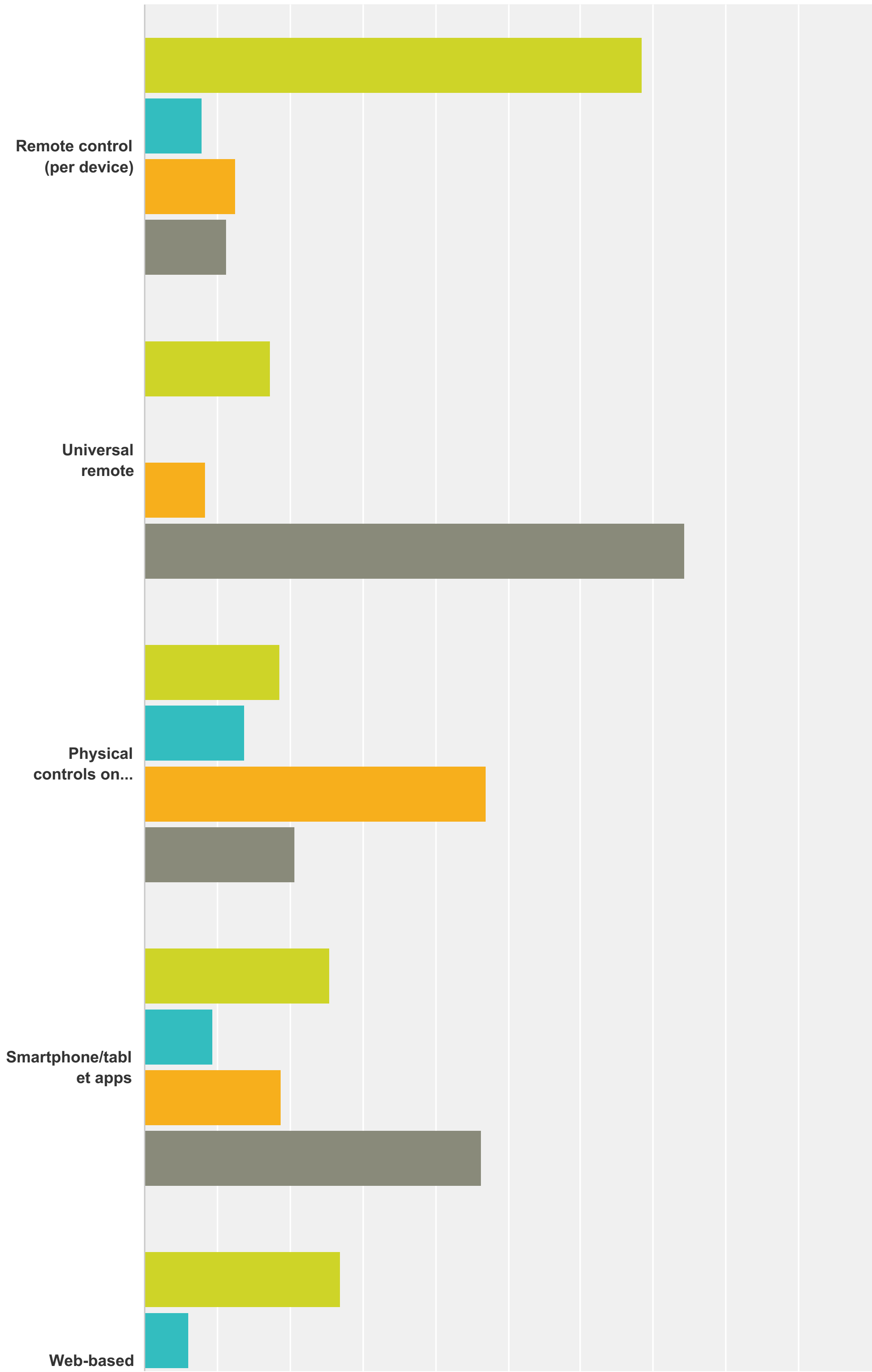
Answered: 164 Skipped: 8

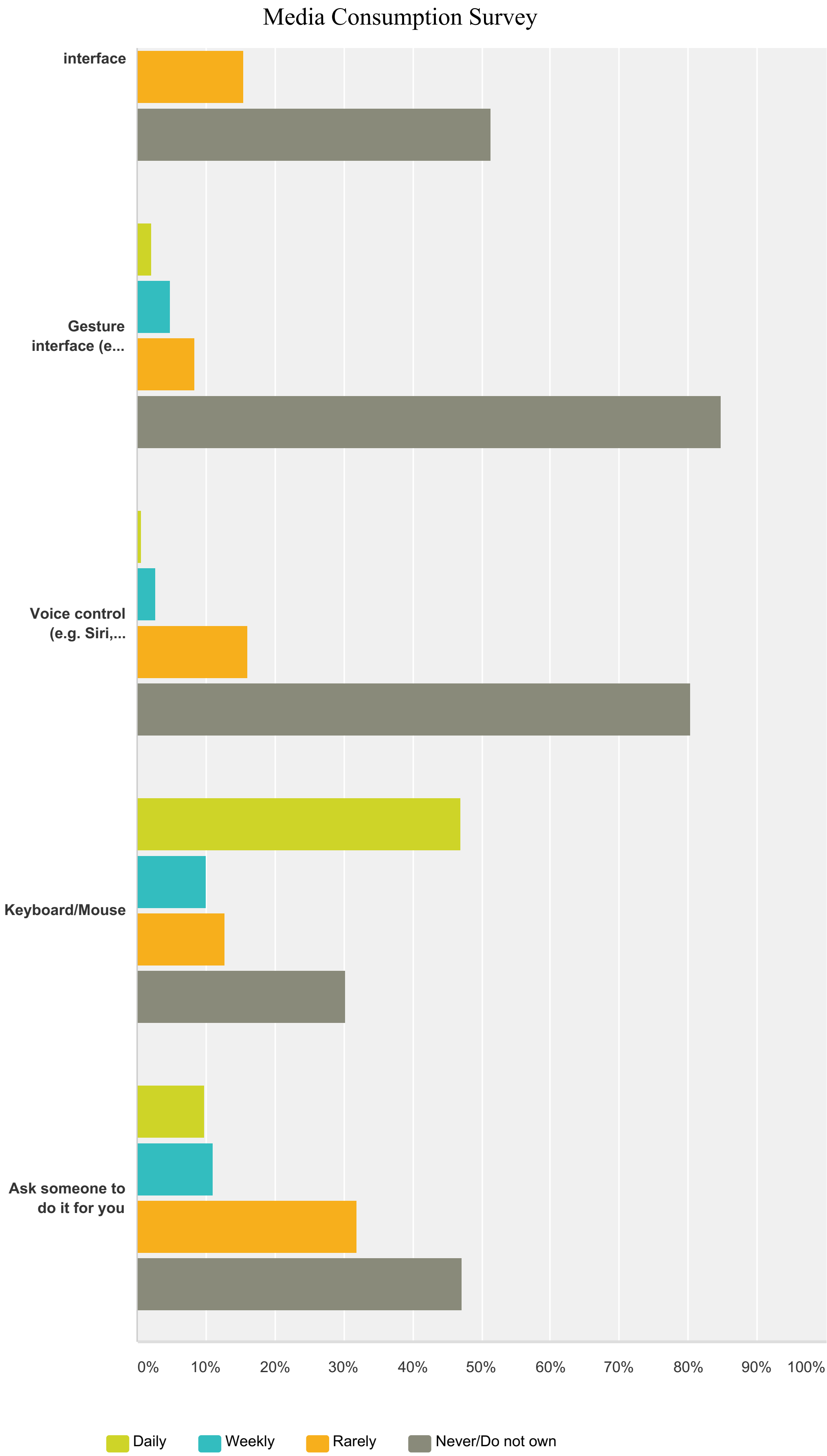


Answer Choices	Responses	
Alone	**20.12%**	33
With Partner	**56.71%**	93
With Parents	**11.59%**	19
With Children	**23.78%**	39
With Flatmates	**10.37%**	17
Total Respondents: 164		

Q5 Which of these control methods do you use to control your TV/set top box/media systems in your household?

Answered: 157 Skipped: 15

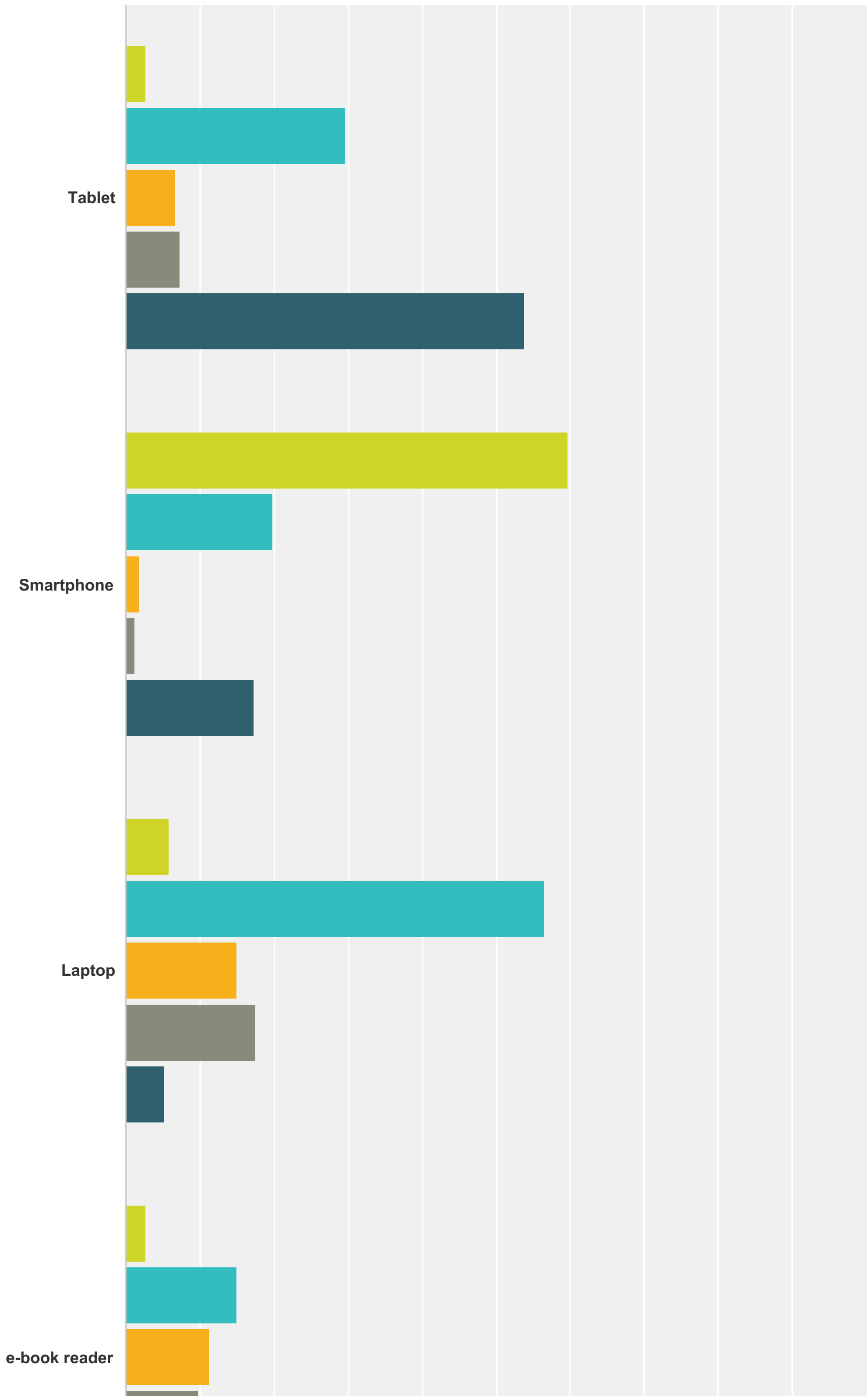



Media Consumption Survey
interface
Gesture interface (e...
Voice control (e.g. Siri,...
Keyboard/Mouse
Ask someone to do it for you
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Daily
Weekly
Rarely
Never/Do not own

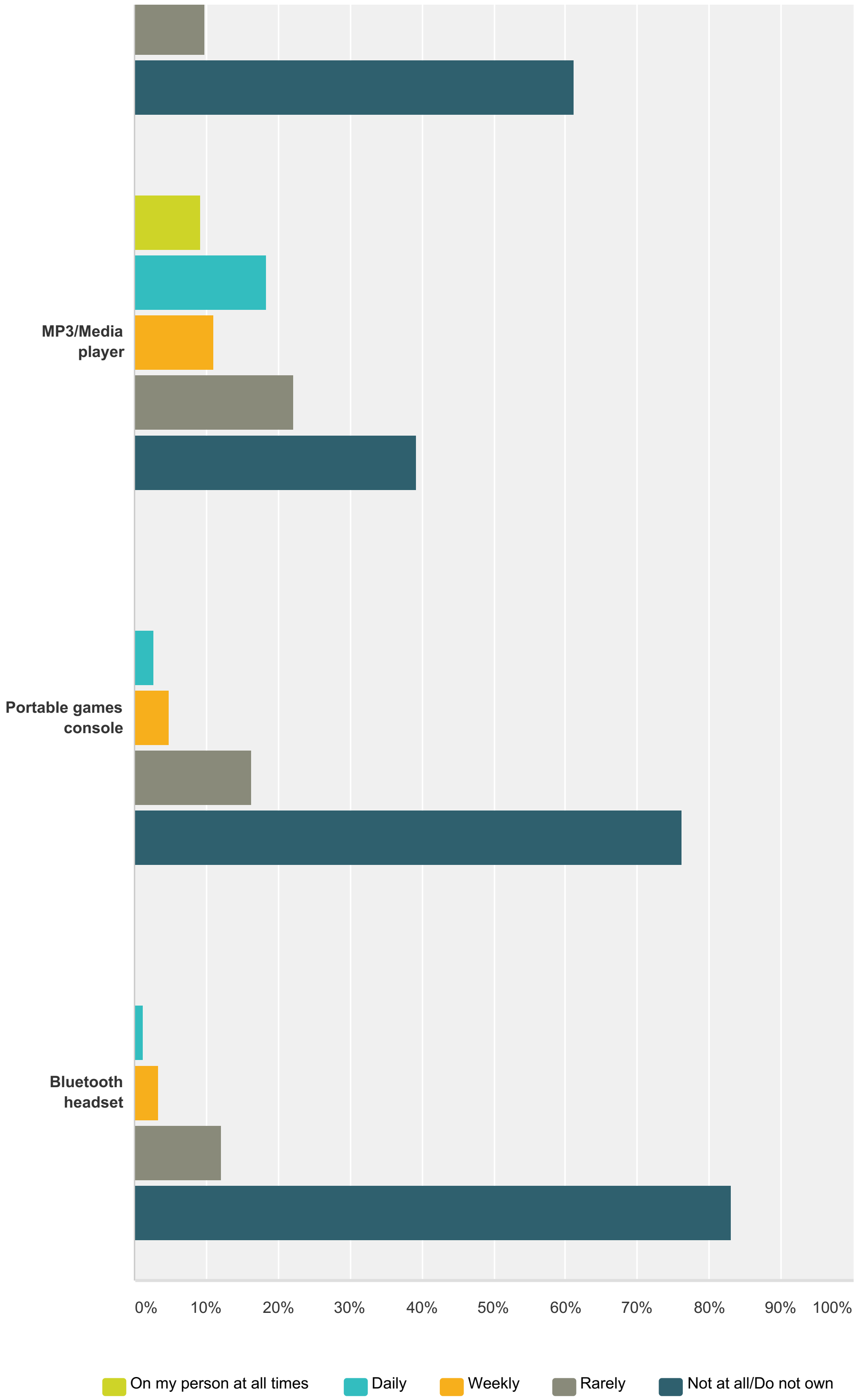
	Daily	Weekly	Rarely	Never/Do not own	Total
Remote control (per device)	**68.42%** 104	**7.89%** 12	**12.50%** 19	**11.18%** 17	152
Universal remote	**17.36%** 25	**0.00%** 0	**8.33%** 12	**74.31%** 107	144
Physical controls on device	**18.62%** 27	**13.79%** 20	**46.90%** 68	**20.69%** 30	145
Smartphone/tablet apps	**25.50%** 38	**9.40%** 14	**18.79%** 28	**46.31%** 69	149
Web-based interface	**27.03%** 40	**6.08%** 9	**15.54%** 23	**51.35%** 76	148
Gesture interface (e.g. Kinect, Samsung SmartTV, wand)	**2.08%** 3	**4.86%** 7	**8.33%** 12	**84.72%** 122	144
Voice control (e.g. Siri, Google Voice Search)	**0.70%** 1	**2.80%** 4	**16.08%** 23	**80.42%** 115	143
Keyboard/Mouse	**46.98%** 70	**10.07%** 15	**12.75%** 19	**30.20%** 45	149
Ask someone to do it for you	**9.72%** 14	**11.11%** 16	**31.94%** 46	**47.22%** 68	144

Q6 Of the following devices, which are you likely to have on your person, and how frequently?

Answered: 157 Skipped: 15



Media Consumption Survey

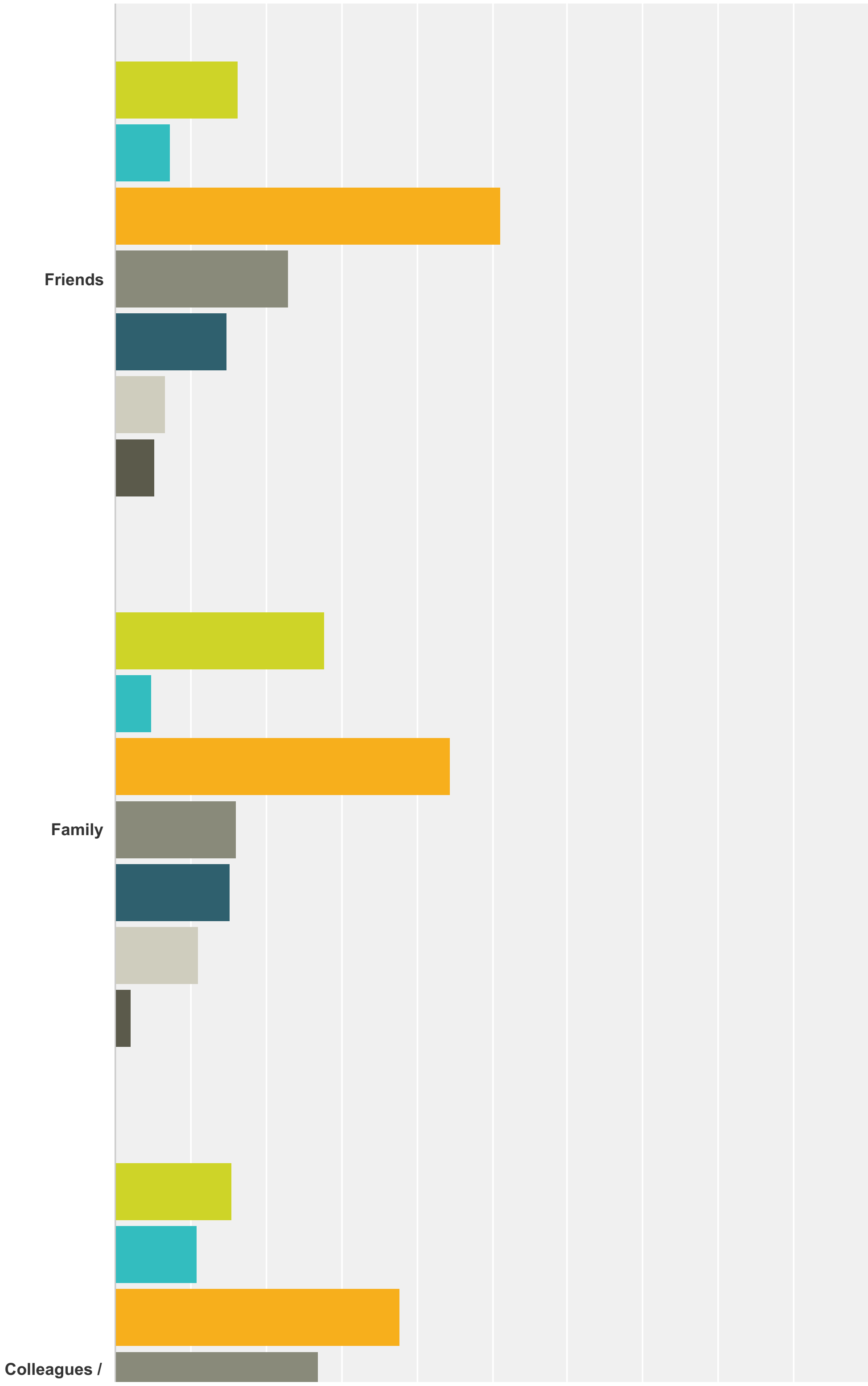


	On my person at all times	Daily	Weekly	Rarely	Not at all/Do not own	Total
Tablet	**2.63%** 4	**29.61%** 45	**6.58%** 10	**7.24%** 11	**53.95%** 82	152

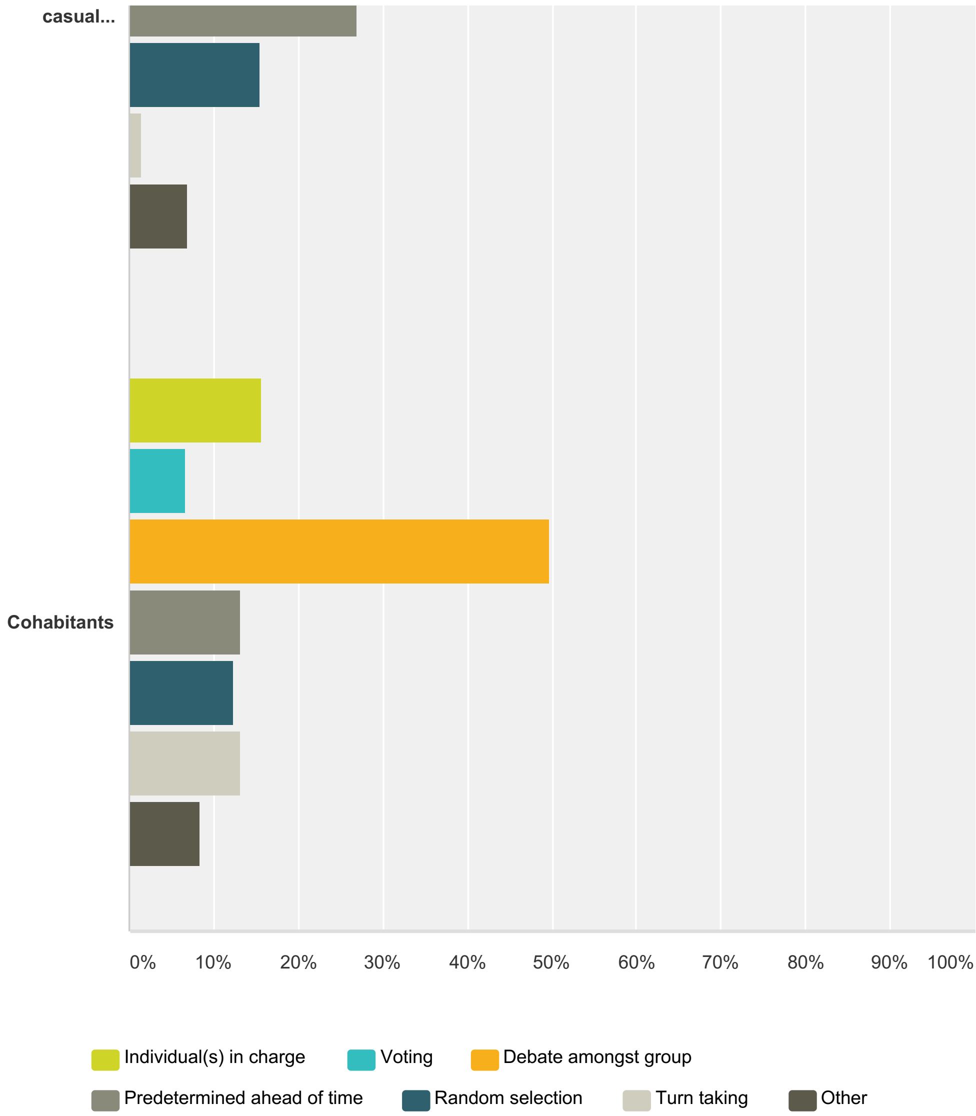
Smartphone	**59.62%** 93	**19.87%** 31	**1.92%** 3	**1.28%** 2	**17.31%** 27	156
Laptop	**5.84%** 9	**56.49%** 87	**14.94%** 23	**17.53%** 27	**5.19%** 8	154
e-book reader	**2.63%** 4	**15.13%** 23	**11.18%** 17	**9.87%** 15	**61.18%** 93	152
MP3/Media player	**9.15%** 14	**18.30%** 28	**11.11%** 17	**22.22%** 34	**39.22%** 60	153
Portable games console	**0.00%** 0	**2.72%** 4	**4.76%** 7	**16.33%** 24	**76.19%** 112	147
Bluetooth headset	**0.00%** 0	**1.35%** 2	**3.38%** 5	**12.16%** 18	**83.11%** 123	148

Q7 In your experience, how are decisions most often made within the following groups, regarding choice of media (e.g. selection of a film, TV program, or game)?

Answered: 145 Skipped: 27



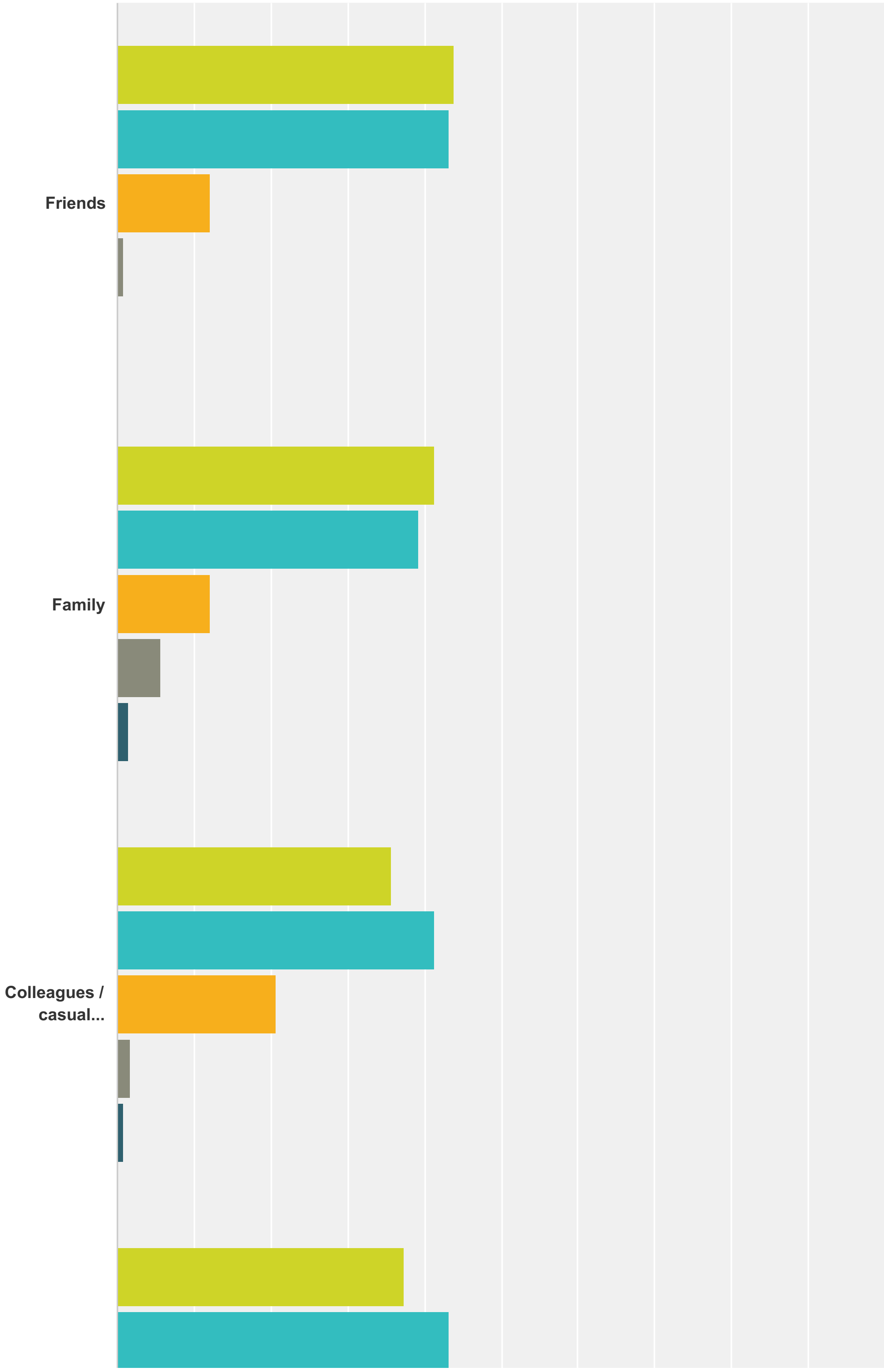
Media Consumption Survey

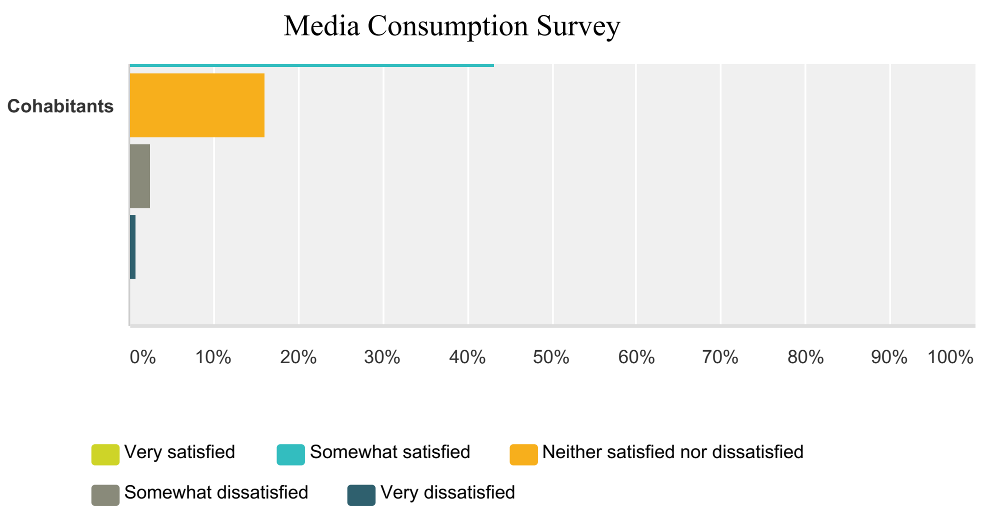


	Individual(s) in charge	Voting	Debate amongst group	Predetermined ahead of time	Random selection	Turn taking	Other	Total Respondents
Friends	**16.30%** 22	**7.41%** 10	**51.11%** 69	**22.96%** 31	**14.81%** 20	**6.67%** 9	**5.19%** 7	135
Family	**27.78%** 40	**4.86%** 7	**44.44%** 64	**15.97%** 23	**15.28%** 22	**11.11%** 16	**2.08%** 3	144
Colleagues / casual acquaintances	**15.38%** 20	**10.77%** 14	**37.69%** 49	**26.92%** 35	**15.38%** 20	**1.54%** 2	**6.92%** 9	130
Cohabitants	**15.70%** 19	**6.61%** 8	**49.59%** 60	**13.22%** 16	**12.40%** 15	**13.22%** 16	**8.26%** 10	121

Q8 How satisfied are you with the way decisions are made within the following groups, regarding choice of media to watch/consume (e.g. selection of a film, TV program, or game)?

Answered: 143 Skipped: 29

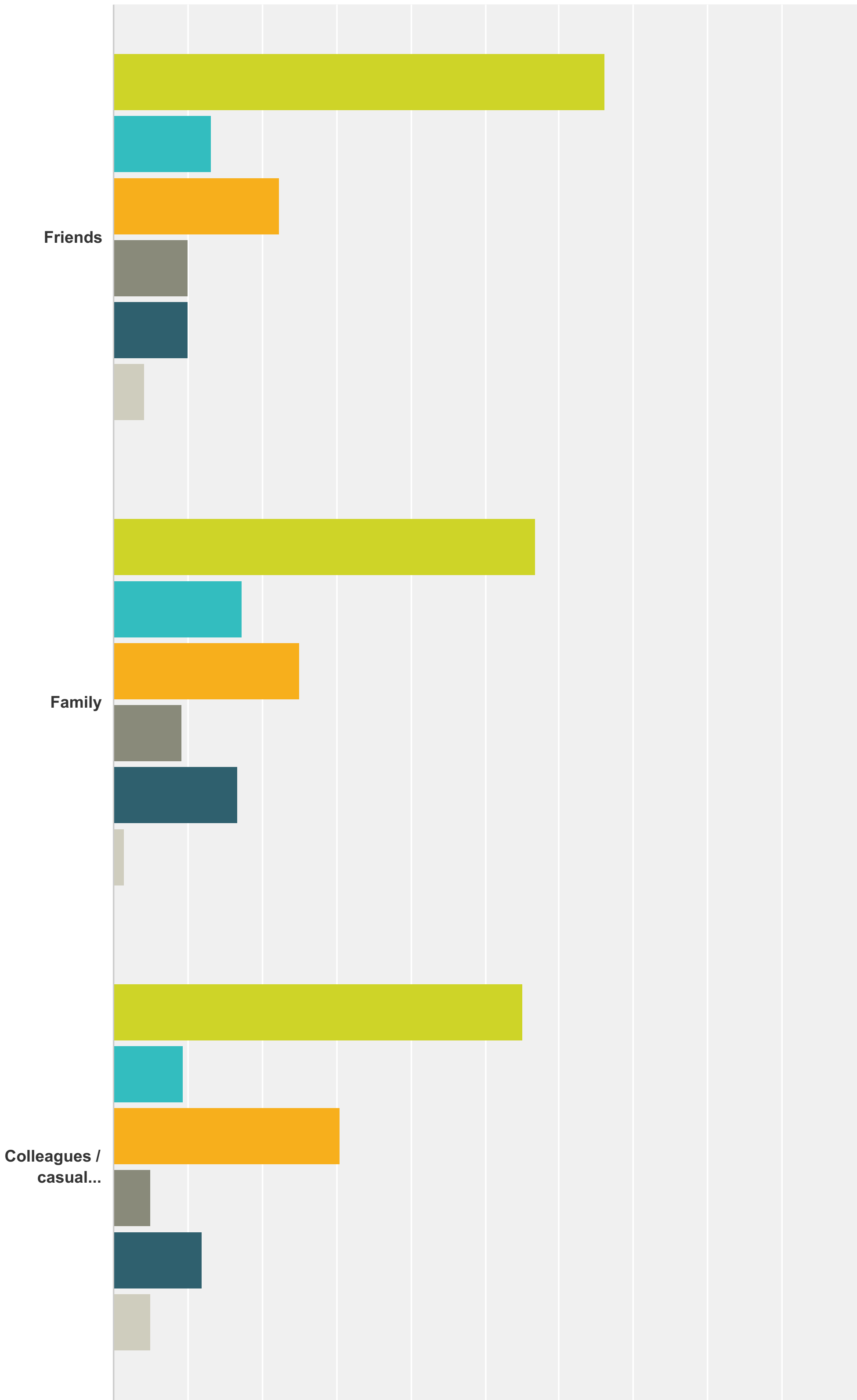




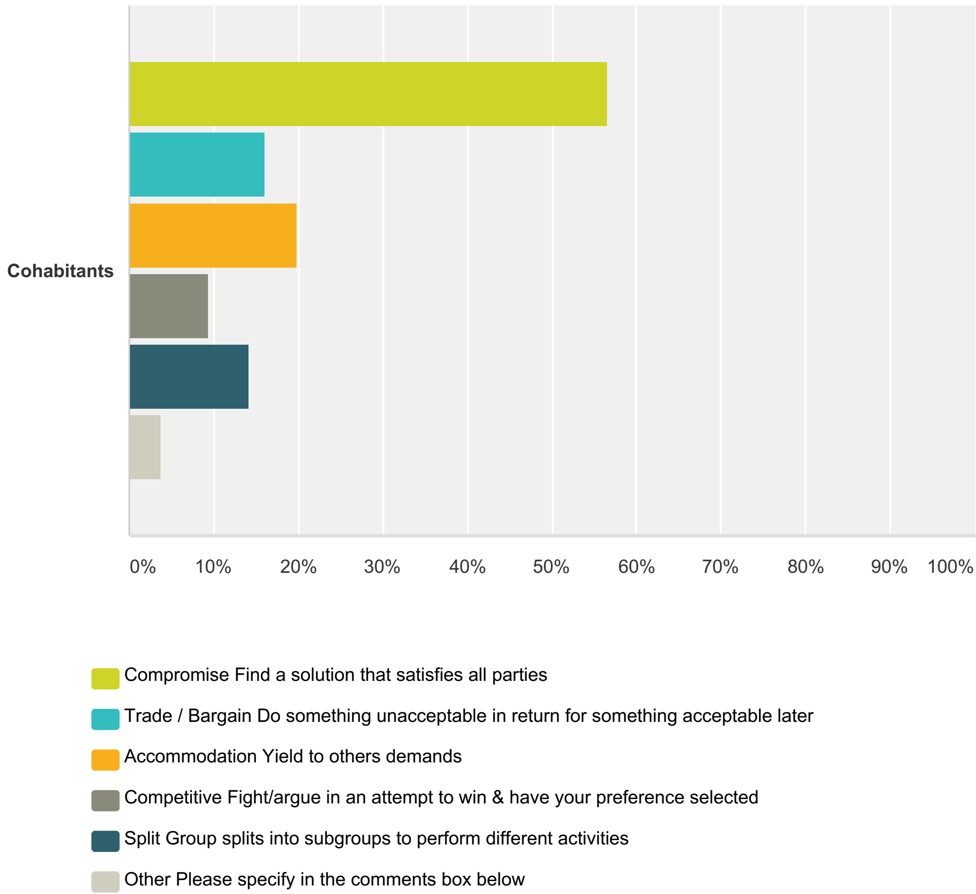
	Very satisfied	Somewhat satisfied	Neither satisfied nor dissatisfied	Somewhat dissatisfied	Very dissatisfied	Total
Friends	**43.94%** 58	**43.18%** 57	**12.12%** 16	**0.76%** 1	**0.00%** 0	132
Family	**41.43%** 58	**39.29%** 55	**12.14%** 17	**5.71%** 8	**1.43%** 2	140
Colleagues / casual acquaintances	**35.71%** 45	**41.27%** 52	**20.63%** 26	**1.59%** 2	**0.79%** 1	126
Cohabitants	**37.29%** 44	**43.22%** 51	**16.10%** 19	**2.54%** 3	**0.85%** 1	118

Q9 Describe how conflicts regarding choice of media to watch/consume are typically resolved, in your experience?

Answered: 133   Skipped: 39



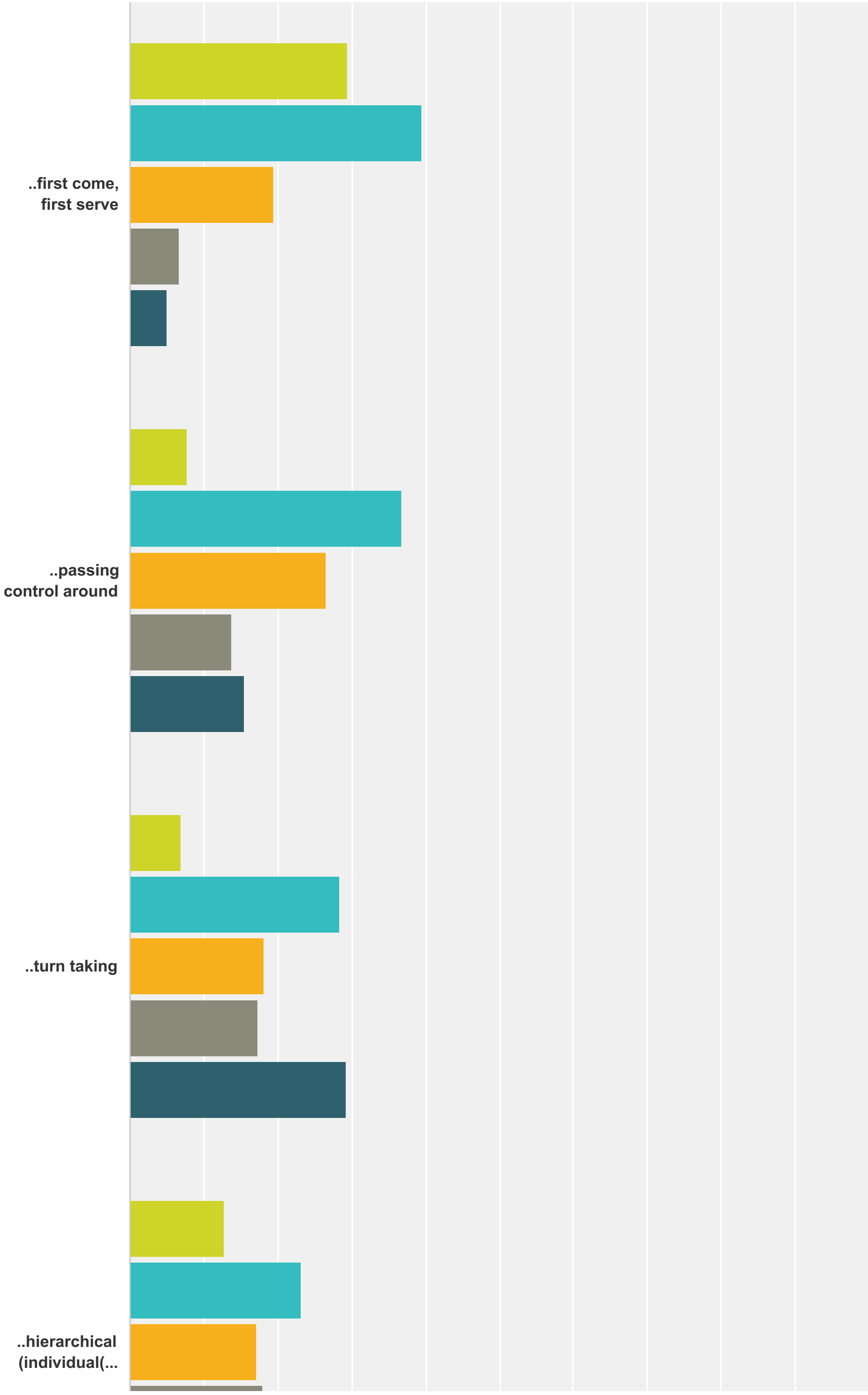
Media Consumption Survey



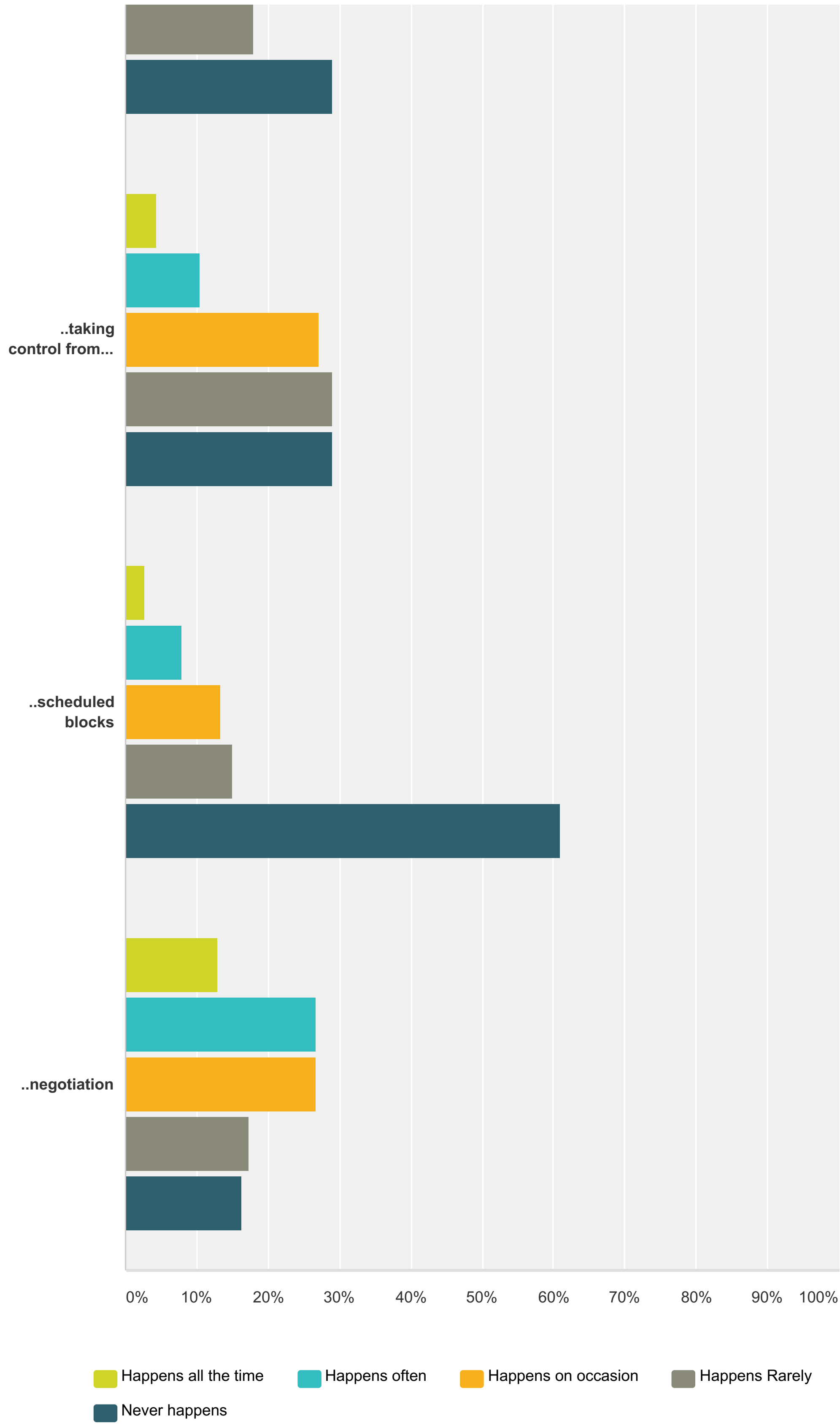
	Compromise Find a solution that satisfies all parties	Trade / Bargain Do something unacceptable in return for something acceptable later	Accommodation Yield to others demands	Competitive Fight/argue in an attempt to win & have your preference selected	Split Group splits into subgroups to perform different activities	Other Please specify in the comments box below	Total Respondents
Friends	**66.12%** 80	**13.22%** 16	**22.31%** 27	**9.92%** 12	**9.92%** 12	**4.13%** 5	121
Family	**56.82%** 75	**17.42%** 23	**25.00%** 33	**9.09%** 12	**16.67%** 22	**1.52%** 2	132
Colleagues / casual acquaintances	**55.08%** 65	**9.32%** 11	**30.51%** 36	**5.08%** 6	**11.86%** 14	**5.08%** 6	118
Cohabitants	**56.60%** 60	**16.04%** 17	**19.81%** 21	**9.43%** 10	**14.15%** 15	**3.77%** 4	106

Q10 How is the control of media systems (e.g. TV, set top box) handled in your home? Is control determined based on...

Answered: 125 Skipped: 47



Media Consumption Survey

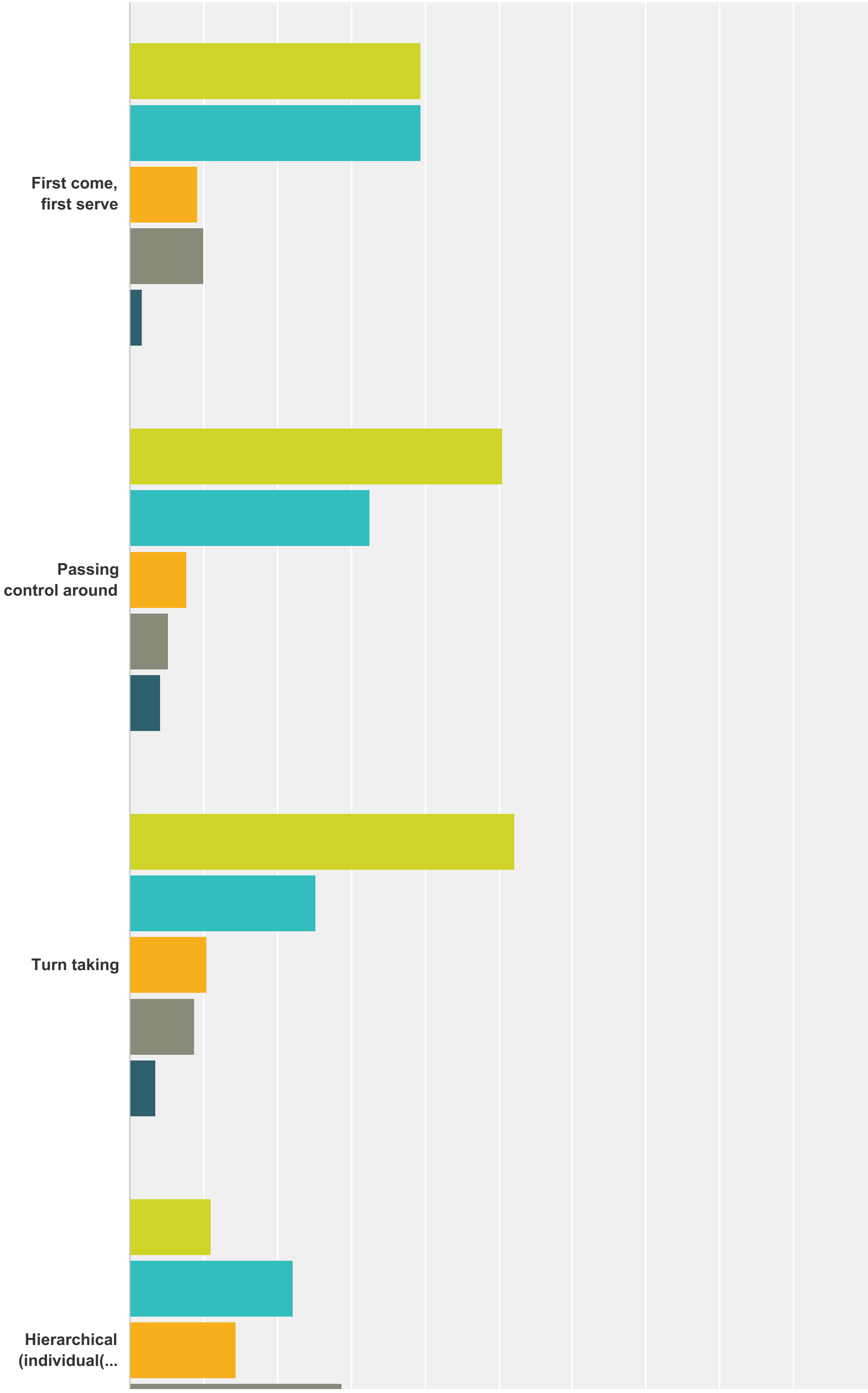


	Happens all the time	Happens often	Happens on occasion	Happens Rarely	Never happens	Total

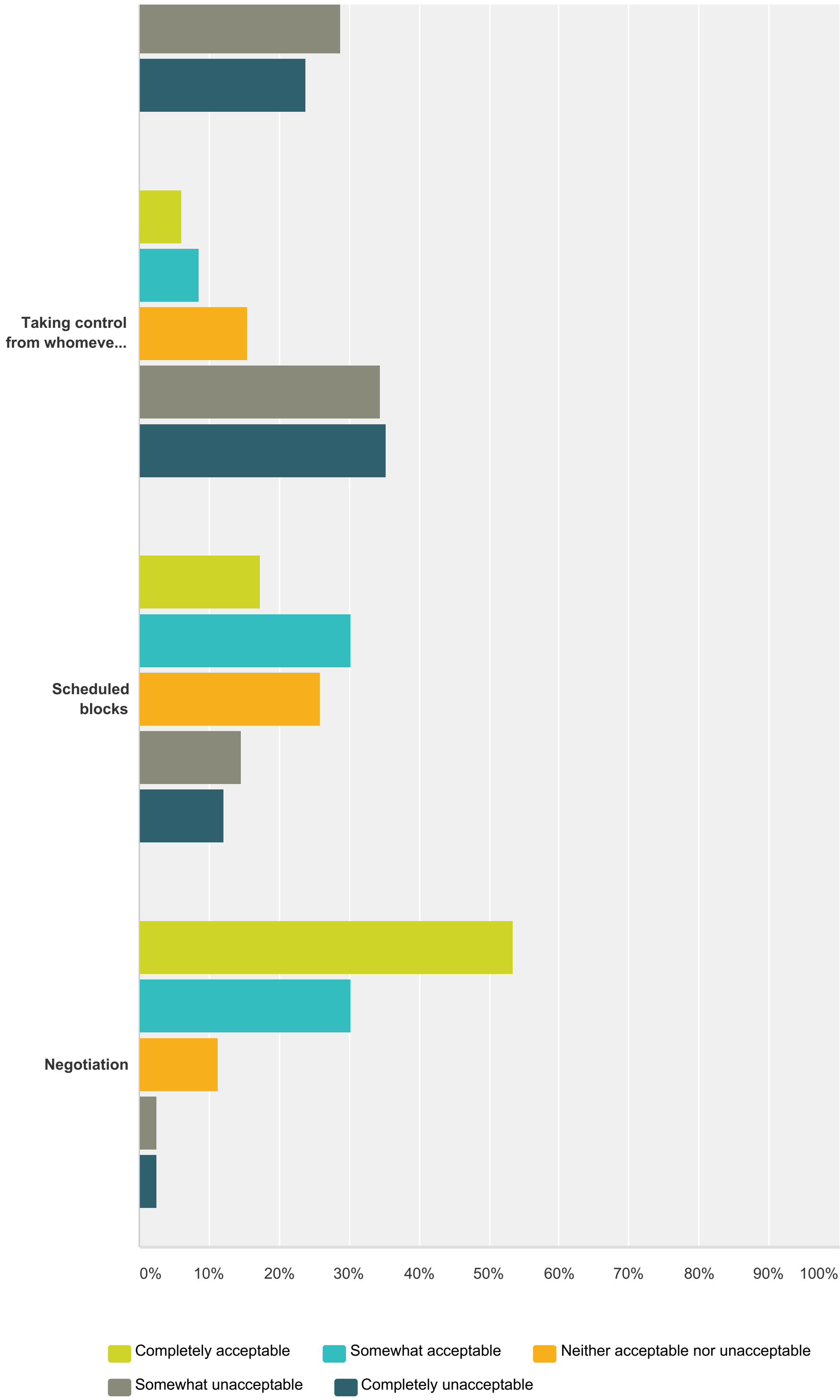
..first come, first serve	**29.41%** 35	**39.50%** 47	**19.33%** 23	**6.72%** 8	**5.04%** 6	119
..passing control around	**7.69%** 9	**36.75%** 43	**26.50%** 31	**13.68%** 16	**15.38%** 18	117
..turn taking	**6.90%** 8	**28.45%** 33	**18.10%** 21	**17.24%** 20	**29.31%** 34	116
..hierarchical (individual(s) in charge)	**12.82%** 15	**23.08%** 27	**17.09%** 20	**17.95%** 21	**29.06%** 34	117
..taking control from whomever currently has it	**4.39%** 5	**10.53%** 12	**27.19%** 31	**28.95%** 33	**28.95%** 33	114
..scheduled blocks	**2.65%** 3	**7.96%** 9	**13.27%** 15	**15.04%** 17	**61.06%** 69	113
..negotiation	**12.93%** 15	**26.72%** 31	**26.72%** 31	**17.24%** 20	**16.38%** 19	116

Q11 How acceptable do you find the following ways of controlling media systems (e.g. tv, set top box)?

Answered: 123   Skipped: 49



Media Consumption Survey

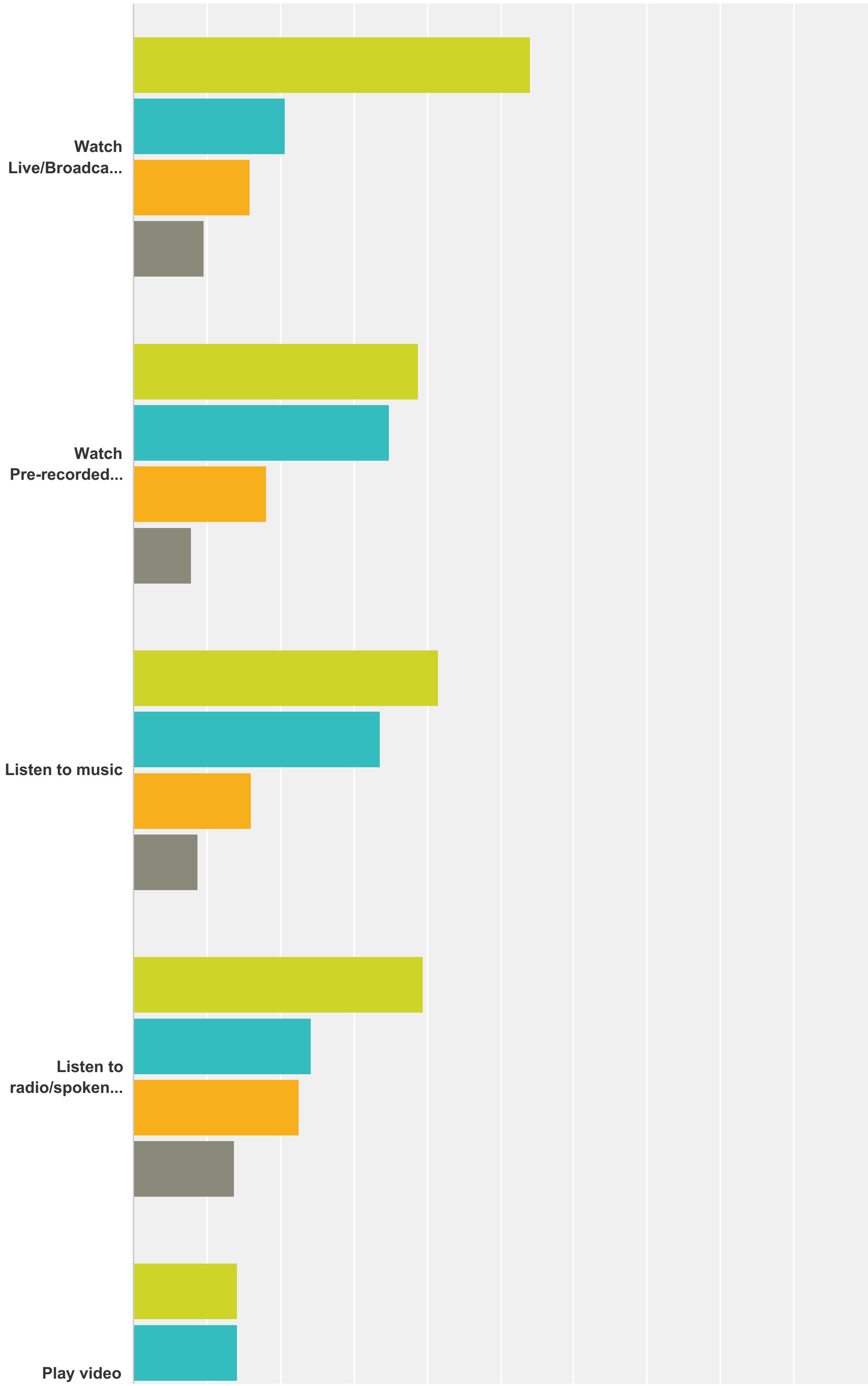


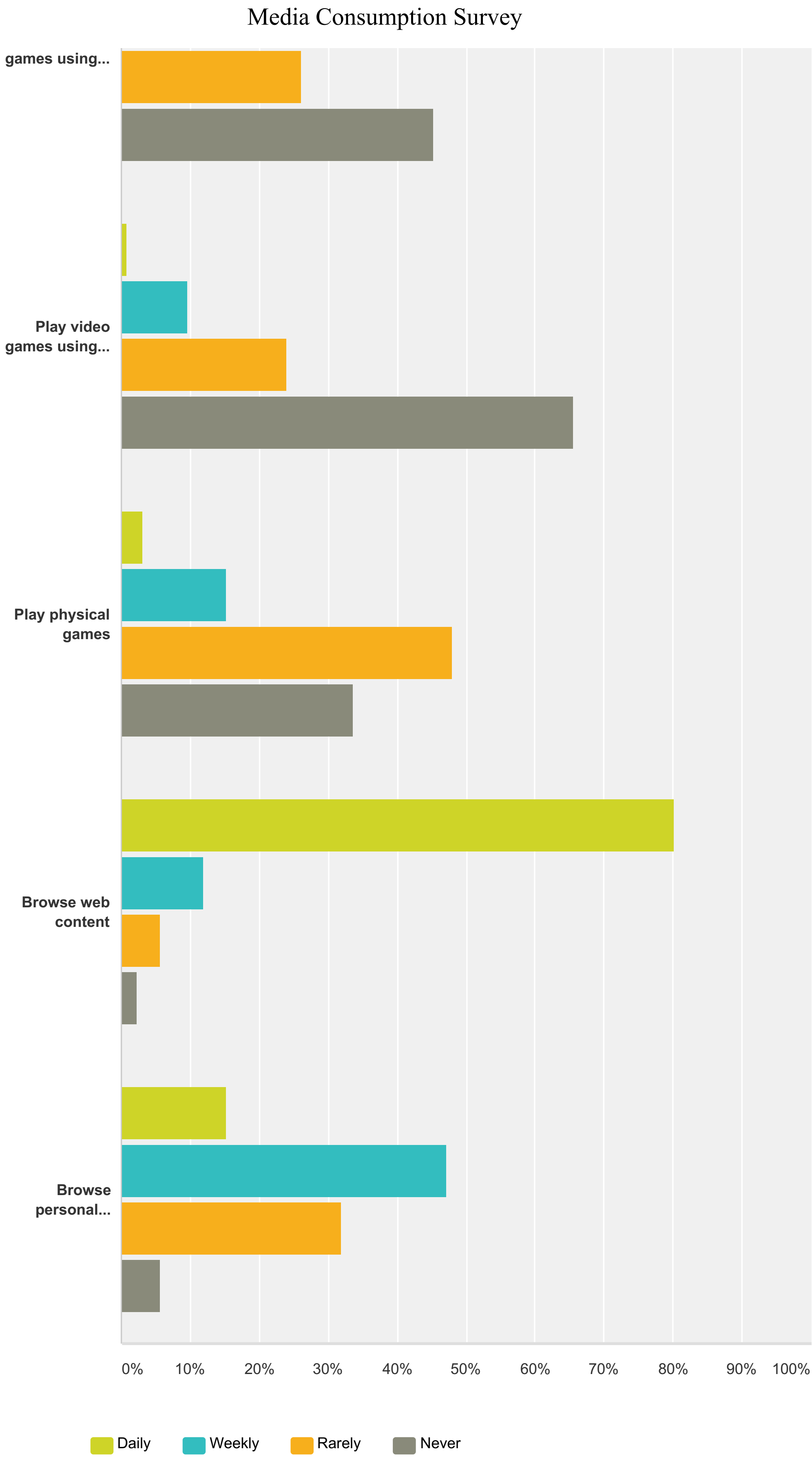
	Completely acceptable	Somewhat acceptable	Neither acceptable nor unacceptable	Somewhat unacceptable	Completely unacceptable	Total

First come, first serve	**39.50%** 47	**39.50%** 47	**9.24%** 11	**10.08%** 12	**1.68%** 2	119
Passing control around	**50.43%** 59	**32.48%** 38	**7.69%** 9	**5.13%** 6	**4.27%** 5	117
Turn taking	**52.17%** 60	**25.22%** 29	**10.43%** 12	**8.70%** 10	**3.48%** 4	115
Hierarchical (individual(s) in charge)	**11.02%** 13	**22.03%** 26	**14.41%** 17	**28.81%** 34	**23.73%** 28	118
Taking control from whomever currently has it	**6.03%** 7	**8.62%** 10	**15.52%** 18	**34.48%** 40	**35.34%** 41	116
Scheduled blocks	**17.24%** 20	**30.17%** 35	**25.86%** 30	**14.66%** 17	**12.07%** 14	116
Negotiation	**53.45%** 62	**30.17%** 35	**11.21%** 13	**2.59%** 3	**2.59%** 3	116

Q12 How often do you perform the following on your own, but with others present, in a private setting like the home?

Answered: 126 Skipped: 46



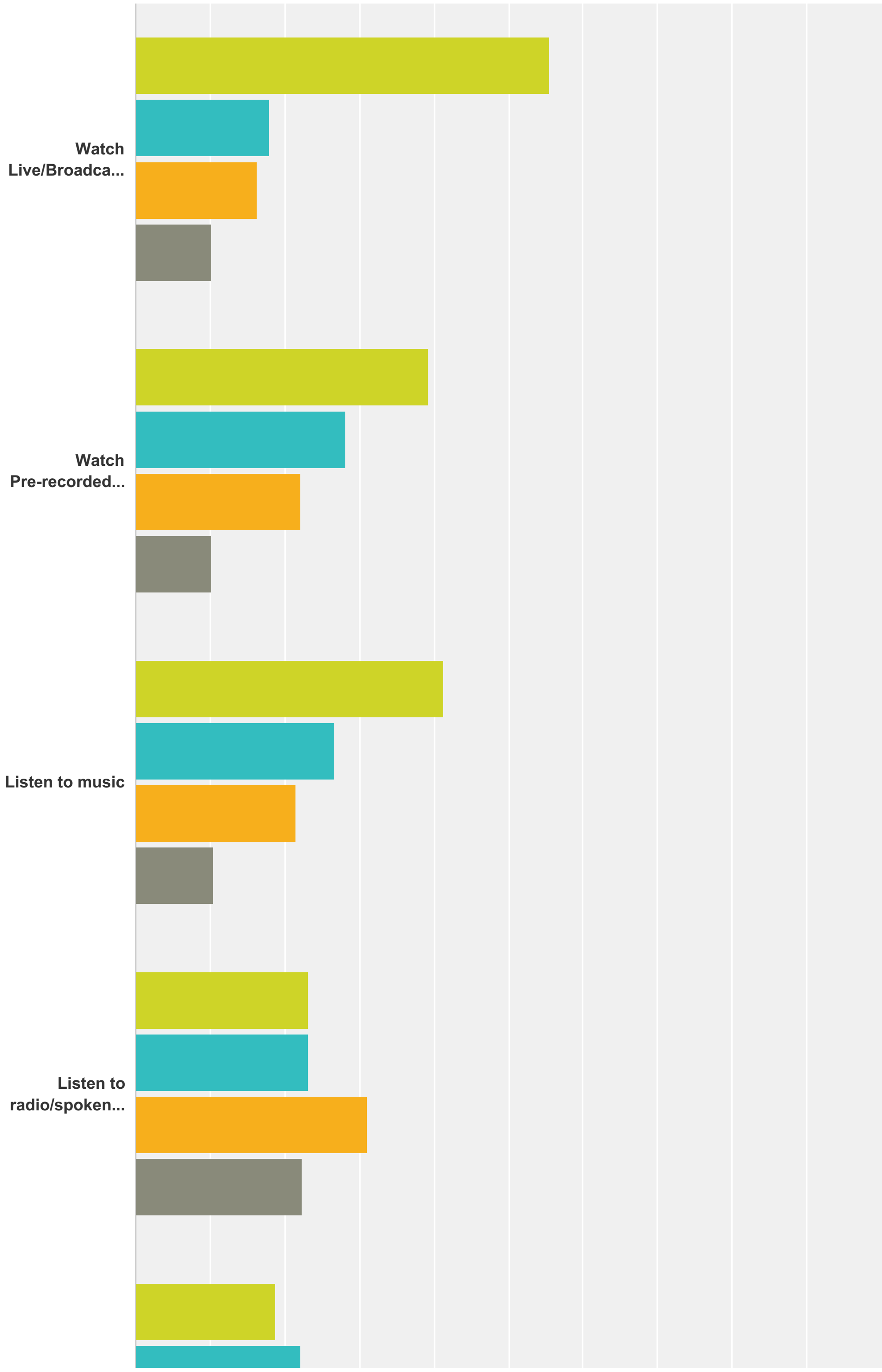

Media Consumption Survey
games using...
Play video games using...
Play physical games
Browse web content
Browse personal...
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Daily
Weekly
Rarely
Never

Media Consumption Survey

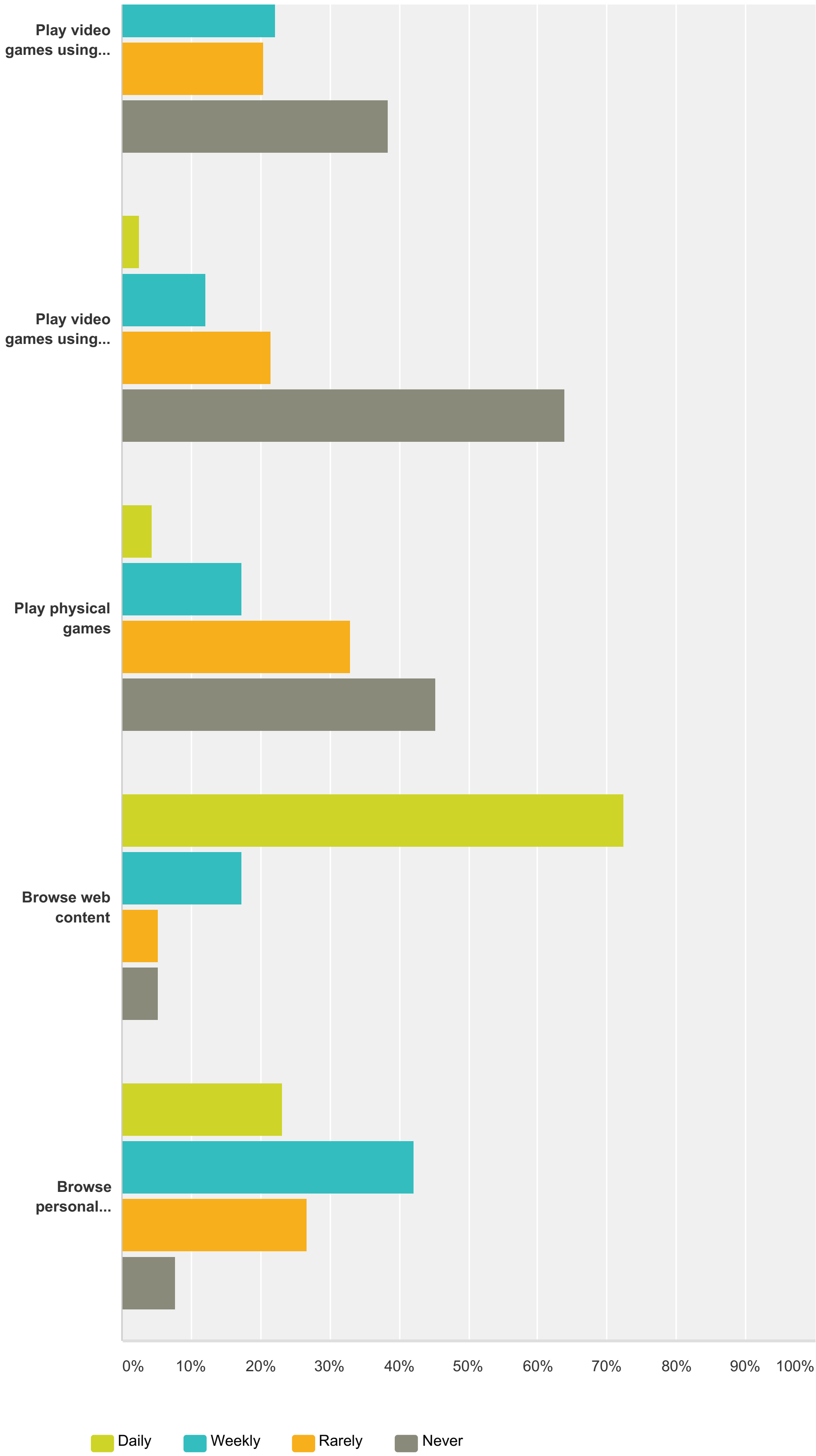
	Daily	Weekly	Rarely	Never	Total
Watch Live/Broadcast TV	**53.97%** 68	**20.63%** 26	**15.87%** 20	**9.52%** 12	126
Watch Pre-recorded TV/Film	**38.89%** 49	**34.92%** 44	**18.25%** 23	**7.94%** 10	126
Listen to music	**41.60%** 52	**33.60%** 42	**16.00%** 20	**8.80%** 11	125
Listen to radio/spoken word	**39.52%** 49	**24.19%** 30	**22.58%** 28	**13.71%** 17	124
Play video games using physical controls	**14.29%** 18	**14.29%** 18	**26.19%** 33	**45.24%** 57	126
Play video games using gestural/motion controls	**0.80%** 1	**9.60%** 12	**24.00%** 30	**65.60%** 82	125
Play physical games	**3.20%** 4	**15.20%** 19	**48.00%** 60	**33.60%** 42	125
Browse web content	**80.16%** 101	**11.90%** 15	**5.56%** 7	**2.38%** 3	126
Browse personal content (e.g. holiday pictures)	**15.20%** 19	**47.20%** 59	**32.00%** 40	**5.60%** 7	125

Q13 How often do others perform the following in your presence, but without you joining in, in a private setting like the home?

Answered: 117 Skipped: 55



Media Consumption Survey

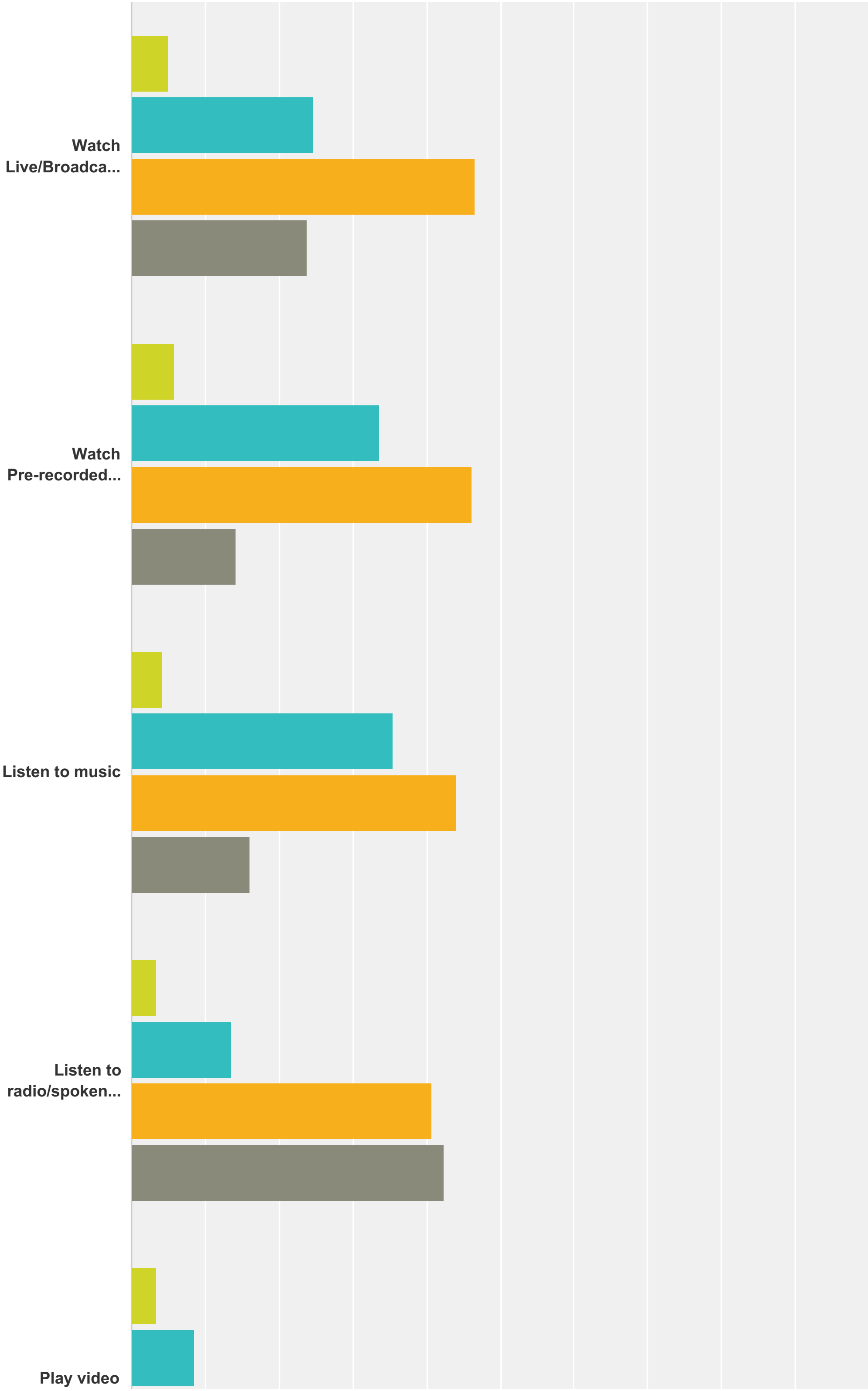


Media Consumption Survey

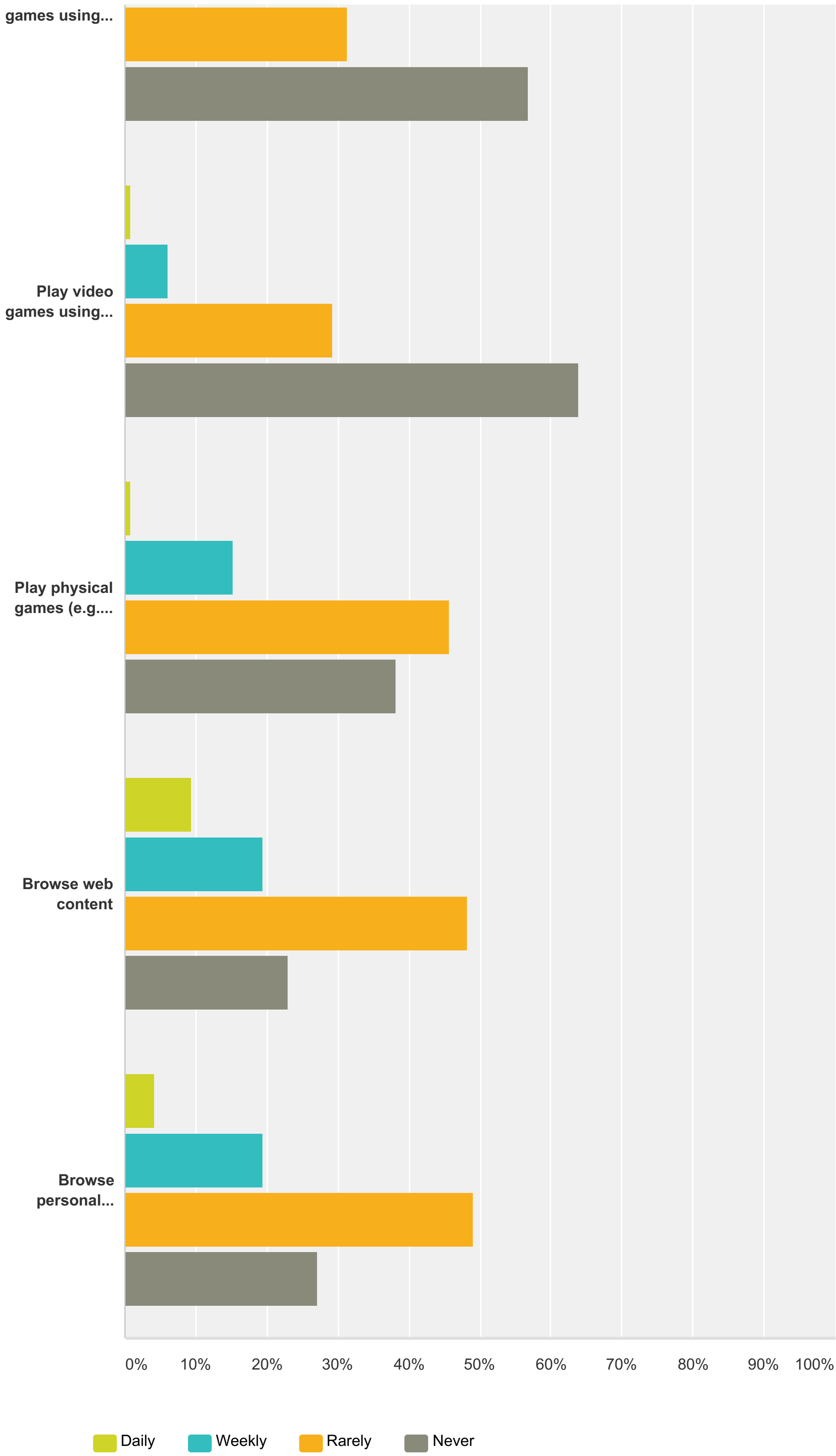
	Daily	Weekly	Rarely	Never	Total
Watch Live/Broadcast TV	**55.56%** 65	**17.95%** 21	**16.24%** 19	**10.26%** 12	117
Watch Pre-recorded TV/Film	**39.32%** 46	**28.21%** 33	**22.22%** 26	**10.26%** 12	117
Listen to music	**41.38%** 48	**26.72%** 31	**21.55%** 25	**10.34%** 12	116
Listen to radio/spoken word	**23.28%** 27	**23.28%** 27	**31.03%** 36	**22.41%** 26	116
Play video games using physical controls	**18.80%** 22	**22.22%** 26	**20.51%** 24	**38.46%** 45	117
Play video games using gestural/motion controls	**2.59%** 3	**12.07%** 14	**21.55%** 25	**63.79%** 74	116
Play physical games	**4.35%** 5	**17.39%** 20	**33.04%** 38	**45.22%** 52	115
Browse web content	**72.41%** 84	**17.24%** 20	**5.17%** 6	**5.17%** 6	116
Browse personal content (e.g. holiday pictures)	**23.28%** 27	**42.24%** 49	**26.72%** 31	**7.76%** 9	116

Q14 How often do you perform the following with friends, in a private setting like the home?

Answered: 119 Skipped: 53



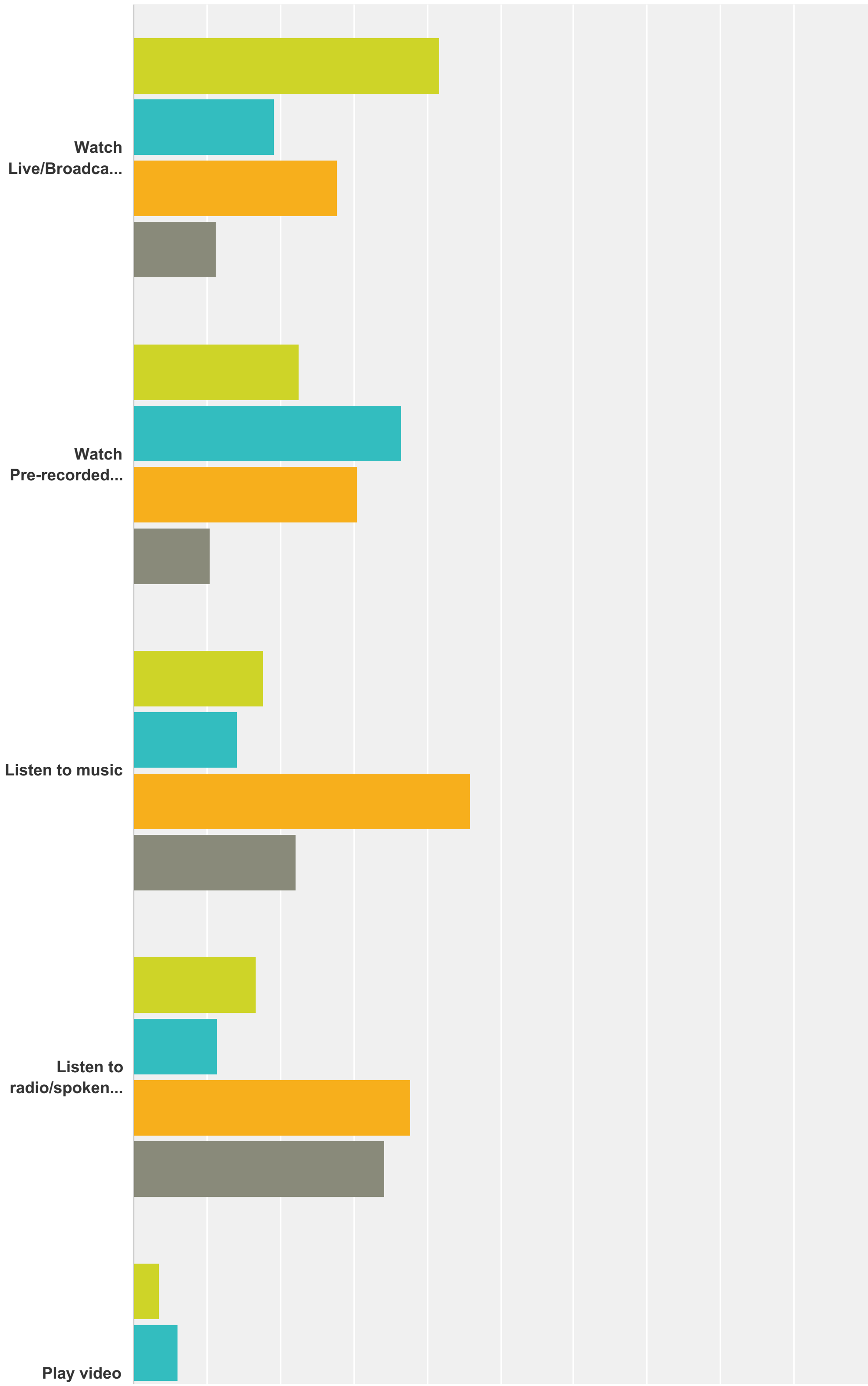
Media Consumption Survey

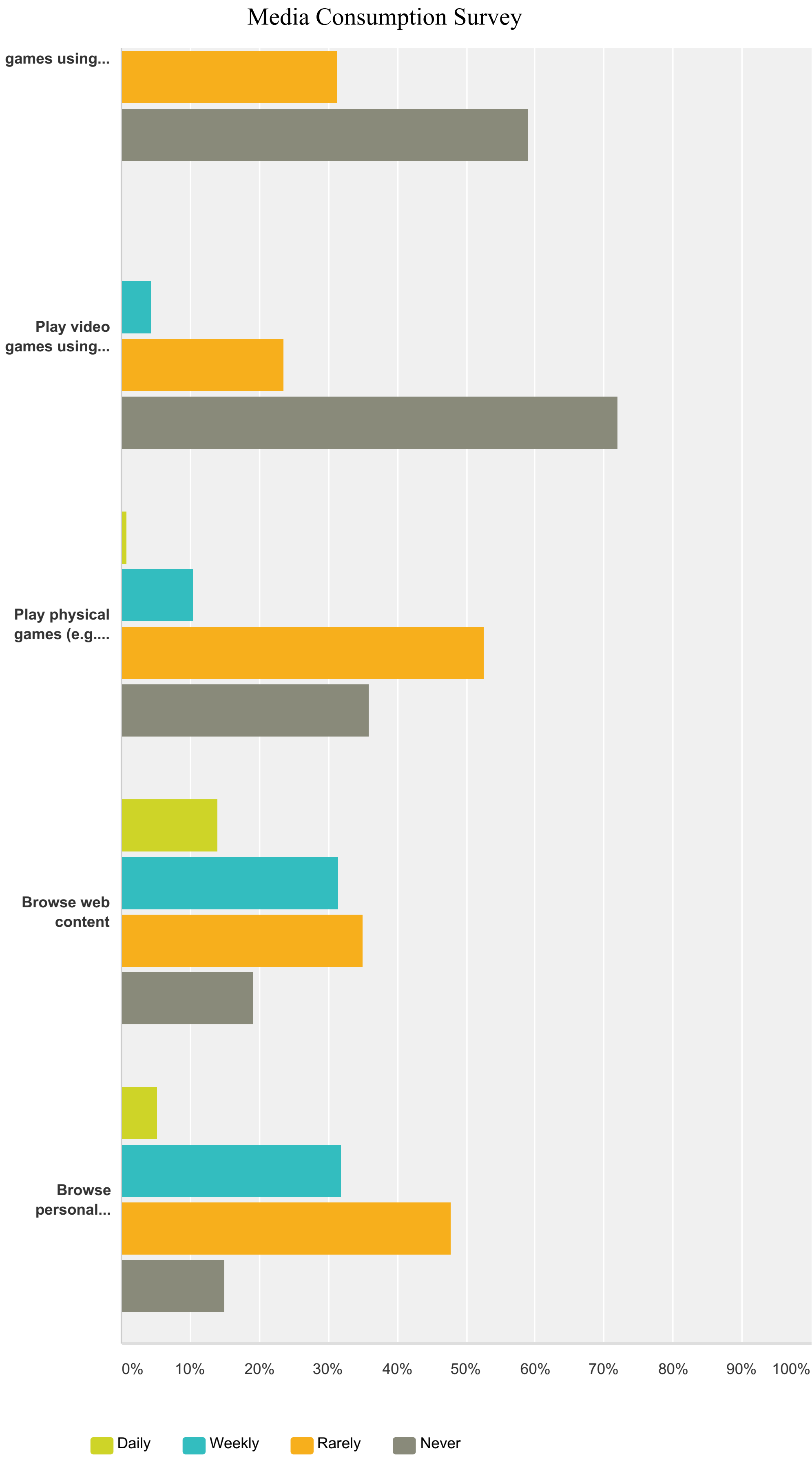


	Daily	Weekly	Rarely	Never	Total
Watch Live/Broadcast TV	**5.08%** 6	**24.58%** 29	**46.61%** 55	**23.73%** 28	118
Watch Pre-recorded TV/Film	**5.88%** 7	**33.61%** 40	**46.22%** 55	**14.29%** 17	119
Listen to music	**4.24%** 5	**35.59%** 42	**44.07%** 52	**16.10%** 19	118
Listen to radio/spoken word	**3.39%** 4	**13.56%** 16	**40.68%** 48	**42.37%** 50	118
Play video games using physical controls	**3.39%** 4	**8.47%** 10	**31.36%** 37	**56.78%** 67	118
Play video games using gestural/motion controls	**0.86%** 1	**6.03%** 7	**29.31%** 34	**63.79%** 74	116
Play physical games (e.g. chess, twister etc.)	**0.85%** 1	**15.25%** 18	**45.76%** 54	**38.14%** 45	118
Browse web content	**9.32%** 11	**19.49%** 23	**48.31%** 57	**22.88%** 27	118
Browse personal content (e.g. holiday pictures)	**4.24%** 5	**19.49%** 23	**49.15%** 58	**27.12%** 32	118

Q15 How often do you perform the following with family, in a private setting like the home?

Answered: 115   Skipped: 57



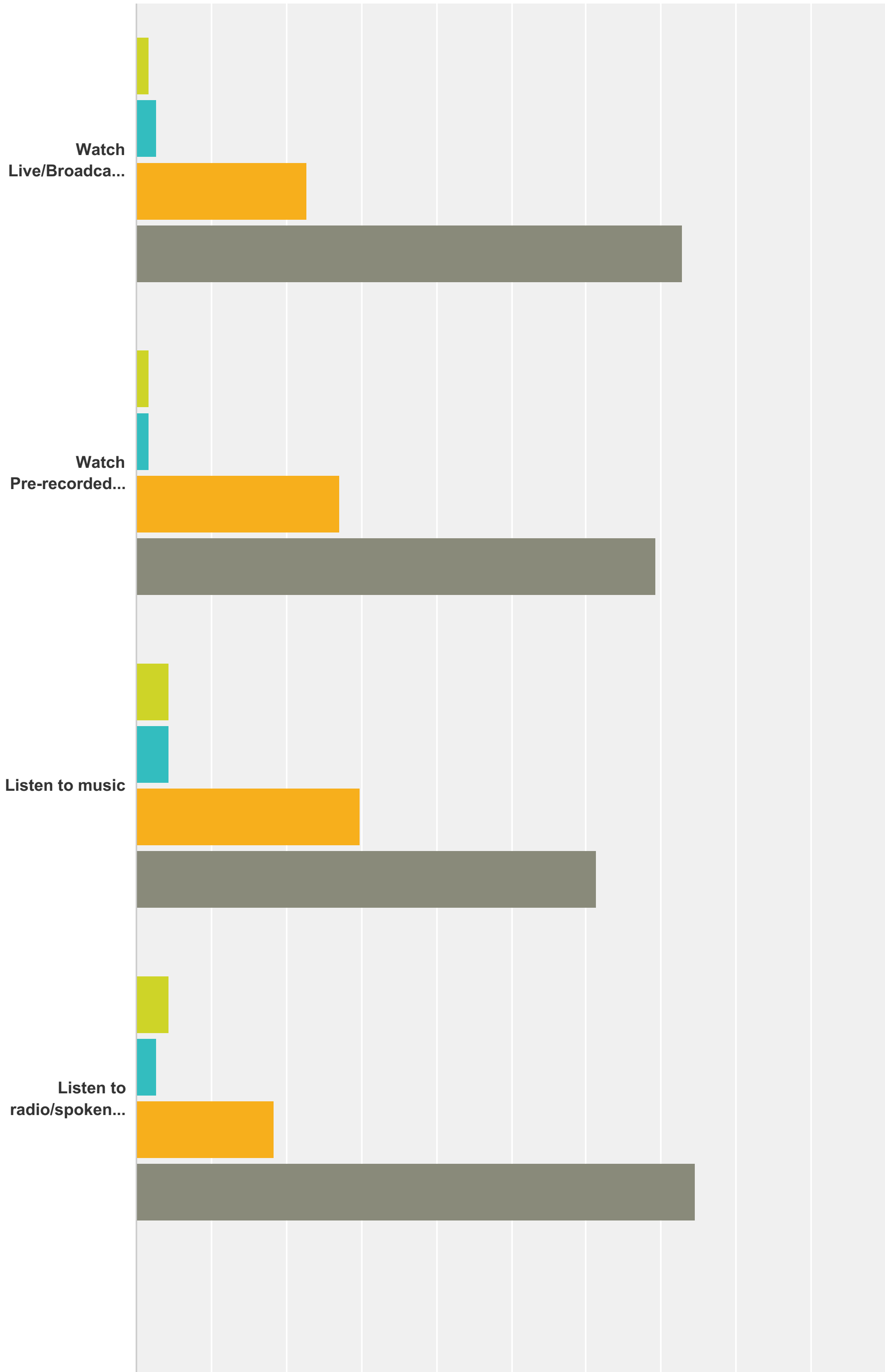

Media Consumption Survey
games using...
Play video games using...
Play physical games (e.g....
Browse web content
Browse personal...
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Daily
Weekly
Rarely
Never

Media Consumption Survey

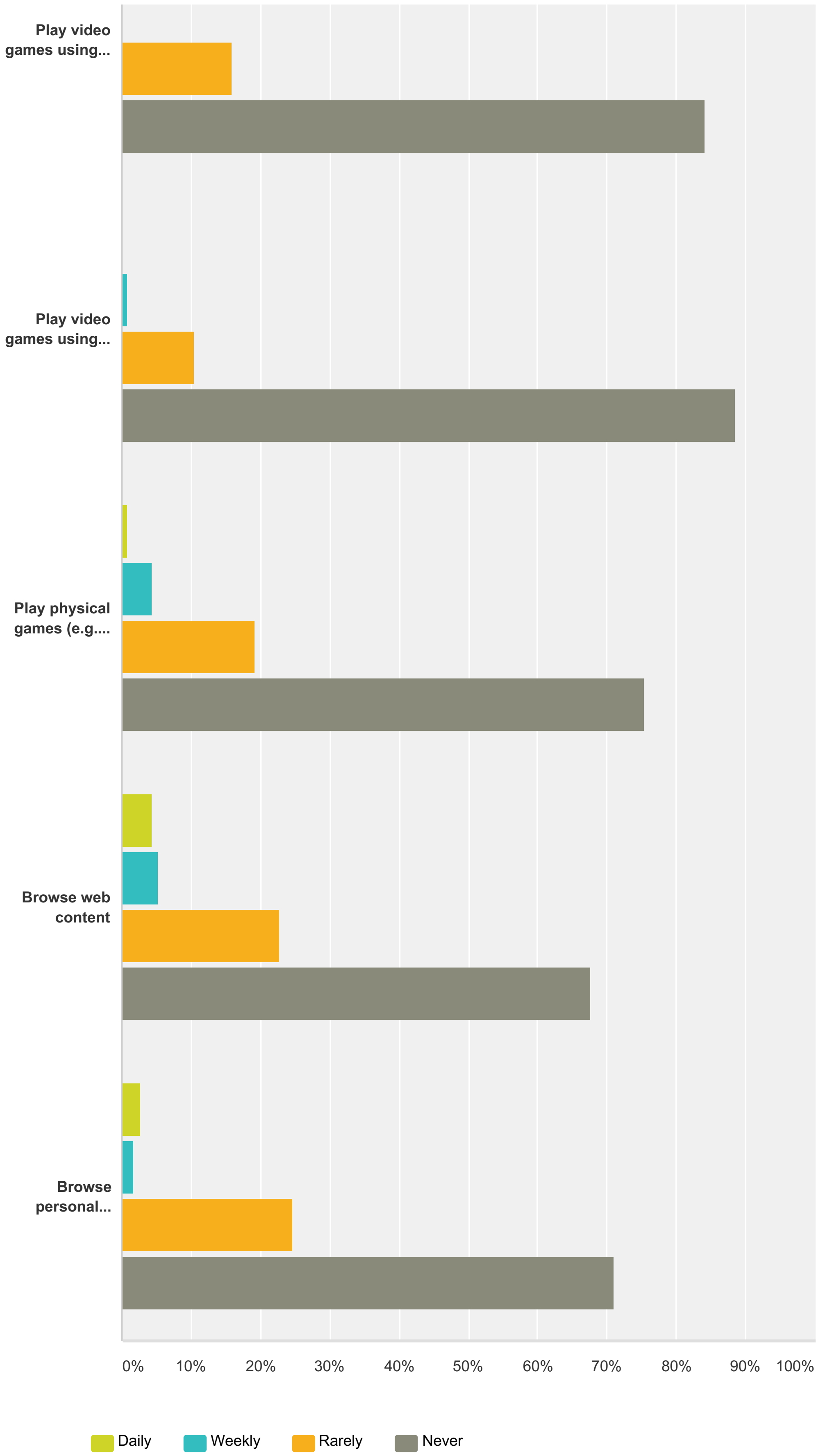
	Daily	Weekly	Rarely	Never	Total
Watch Live/Broadcast TV	**41.74%** 48	**19.13%** 22	**27.83%** 32	**11.30%** 13	115
Watch Pre-recorded TV/Film	**22.61%** 26	**36.52%** 42	**30.43%** 35	**10.43%** 12	115
Listen to music	**17.70%** 20	**14.16%** 16	**46.02%** 52	**22.12%** 25	113
Listen to radio/spoken word	**16.67%** 19	**11.40%** 13	**37.72%** 43	**34.21%** 39	114
Play video games using physical controls	**3.48%** 4	**6.09%** 7	**31.30%** 36	**59.13%** 68	115
Play video games using gestural/motion controls	**0.00%** 0	**4.39%** 5	**23.68%** 27	**71.93%** 82	114
Play physical games (e.g. chess, twister etc.)	**0.88%** 1	**10.53%** 12	**52.63%** 60	**35.96%** 41	114
Browse web content	**14.04%** 16	**31.58%** 36	**35.09%** 40	**19.30%** 22	114
Browse personal content (e.g. holiday pictures)	**5.31%** 6	**31.86%** 36	**47.79%** 54	**15.04%** 17	113

Q16 How often do you perform the following with work colleagues or casual acquaintances, in a private setting like the home?

Answered: 114 Skipped: 58



Media Consumption Survey

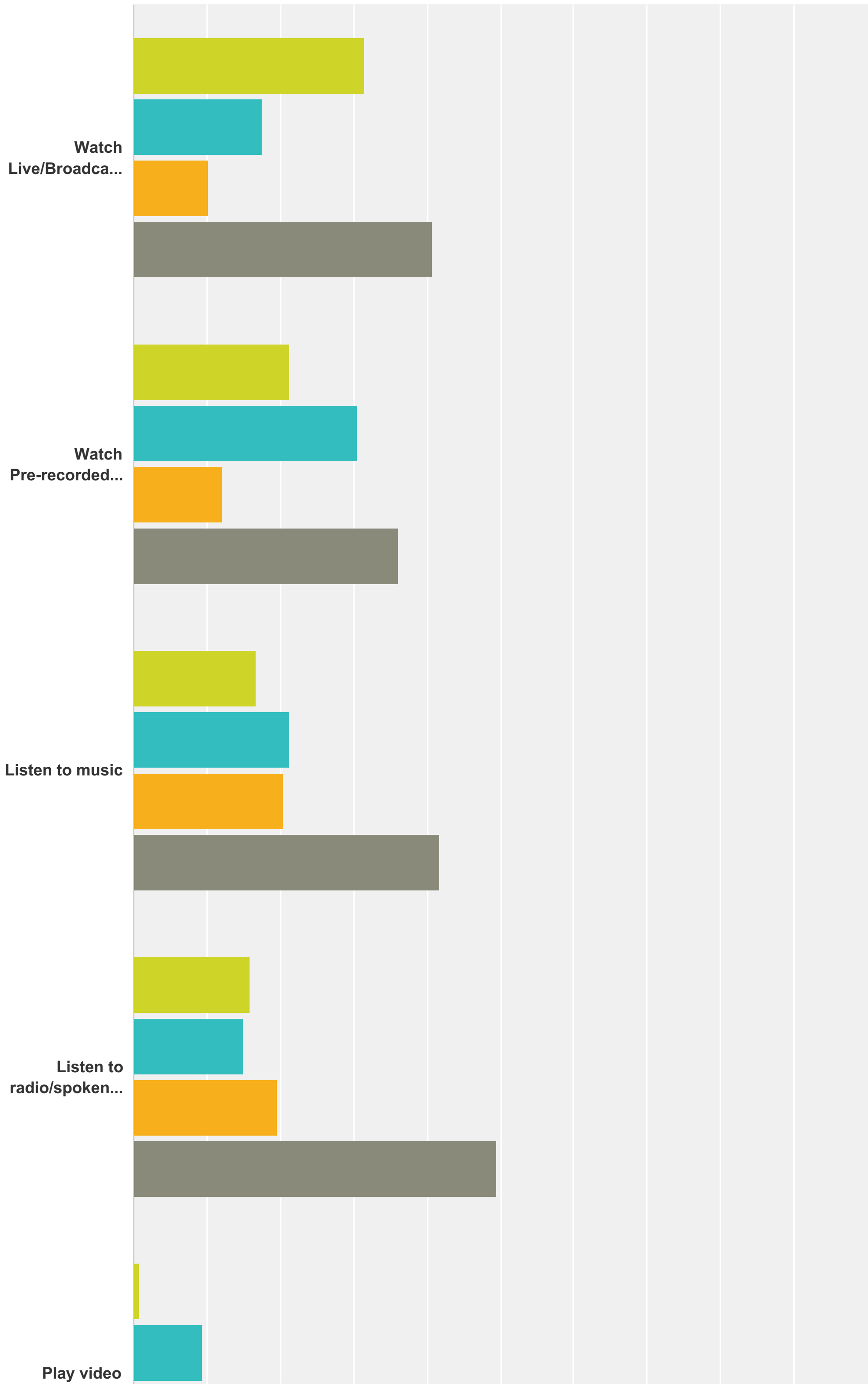


Media Consumption Survey

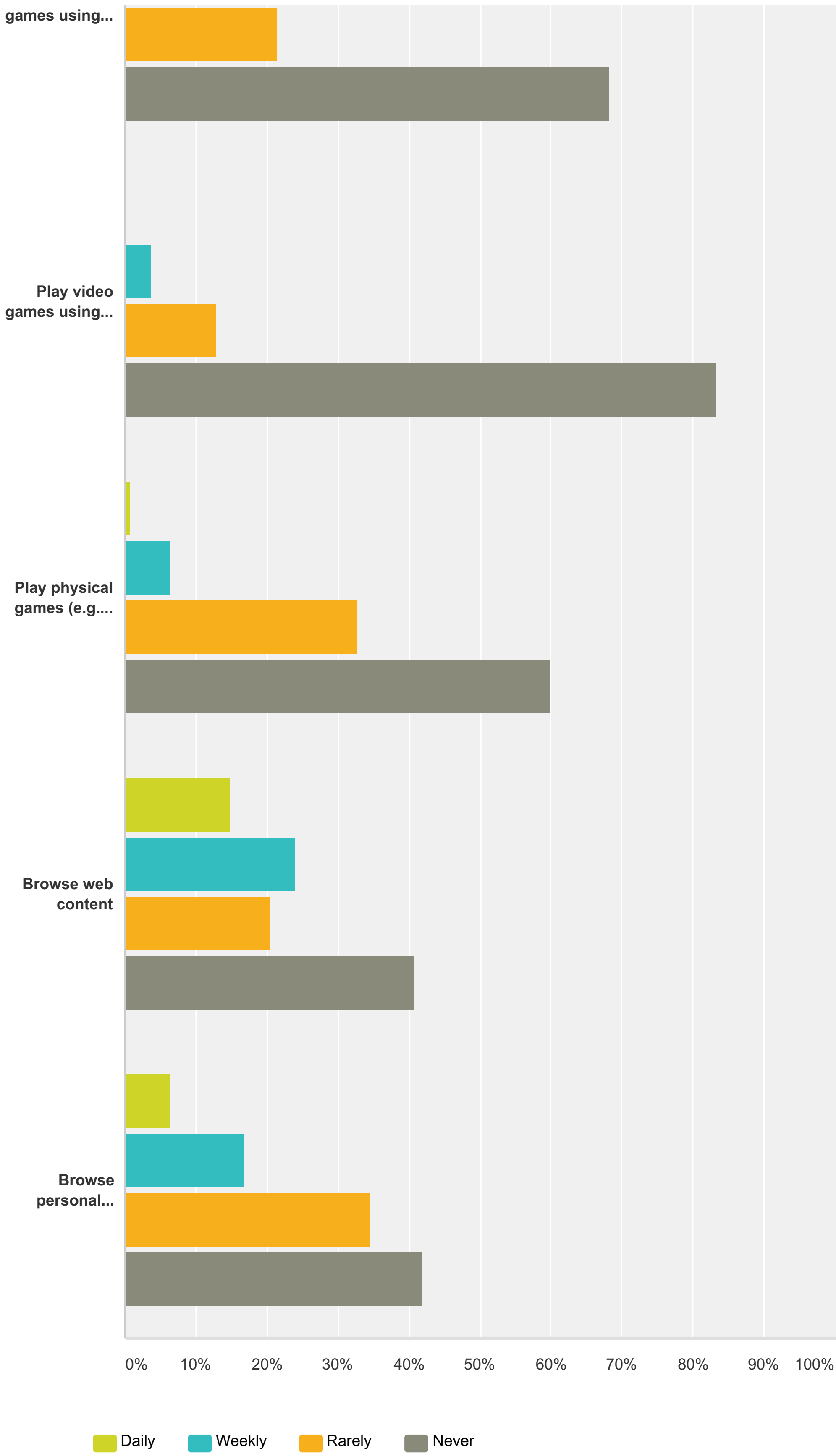
	Daily	Weekly	Rarely	Never	Total
Watch Live/Broadcast TV	**1.75%** 2	**2.63%** 3	**22.81%** 26	**72.81%** 83	114
Watch Pre-recorded TV/Film	**1.75%** 2	**1.75%** 2	**27.19%** 31	**69.30%** 79	114
Listen to music	**4.39%** 5	**4.39%** 5	**29.82%** 34	**61.40%** 70	114
Listen to radio/spoken word	**4.39%** 5	**2.63%** 3	**18.42%** 21	**74.56%** 85	114
Play video games using physical controls	**0.00%** 0	**0.00%** 0	**15.79%** 18	**84.21%** 96	114
Play video games using gestural/motion controls	**0.00%** 0	**0.88%** 1	**10.53%** 12	**88.60%** 101	114
Play physical games (e.g. chess, twister etc.)	**0.88%** 1	**4.39%** 5	**19.30%** 22	**75.44%** 86	114
Browse web content	**4.39%** 5	**5.26%** 6	**22.81%** 26	**67.54%** 77	114
Browse personal content (e.g. holiday pictures)	**2.63%** 3	**1.75%** 2	**24.56%** 28	**71.05%** 81	114

Q17 How often do you perform the following with cohabitants, in a private setting like the home?

Answered: 108 Skipped: 64



Media Consumption Survey



Media Consumption Survey

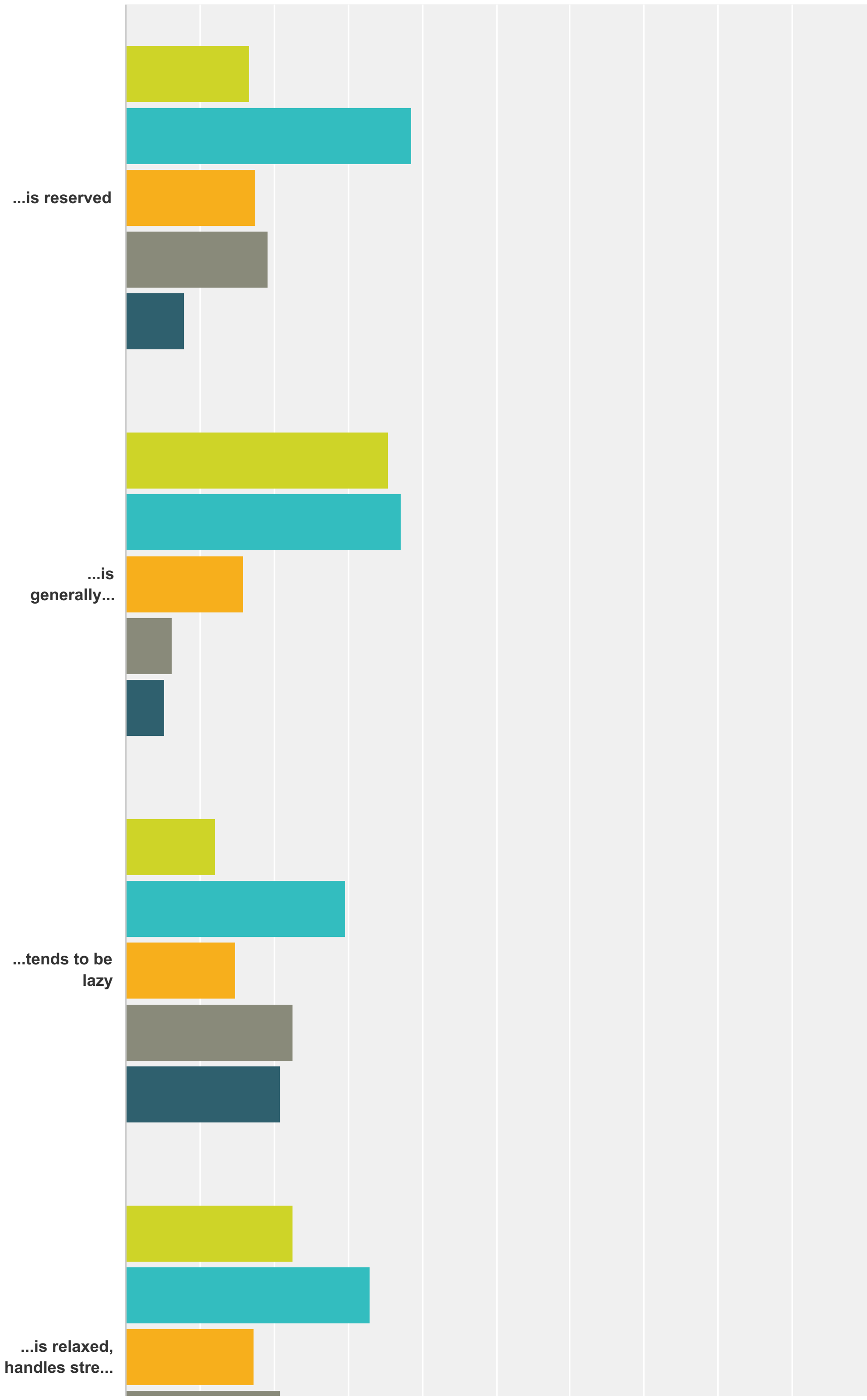
	Daily	Weekly	Rarely	Never	Total
Watch Live/Broadcast TV	**31.48%** 34	**17.59%** 19	**10.19%** 11	**40.74%** 44	108
Watch Pre-recorded TV/Film	**21.30%** 23	**30.56%** 33	**12.04%** 13	**36.11%** 39	108
Listen to music	**16.67%** 18	**21.30%** 23	**20.37%** 22	**41.67%** 45	108
Listen to radio/spoken word	**15.89%** 17	**14.95%** 16	**19.63%** 21	**49.53%** 53	107
Play video games using physical controls	**0.93%** 1	**9.35%** 10	**21.50%** 23	**68.22%** 73	107
Play video games using gestural/motion controls	**0.00%** 0	**3.70%** 4	**12.96%** 14	**83.33%** 90	108
Play physical games (e.g. chess, twister etc.)	**0.93%** 1	**6.54%** 7	**32.71%** 35	**59.81%** 64	107
Browse web content	**14.81%** 16	**24.07%** 26	**20.37%** 22	**40.74%** 44	108
Browse personal content (e.g. holiday pictures)	**6.54%** 7	**16.82%** 18	**34.58%** 37	**42.06%** 45	107

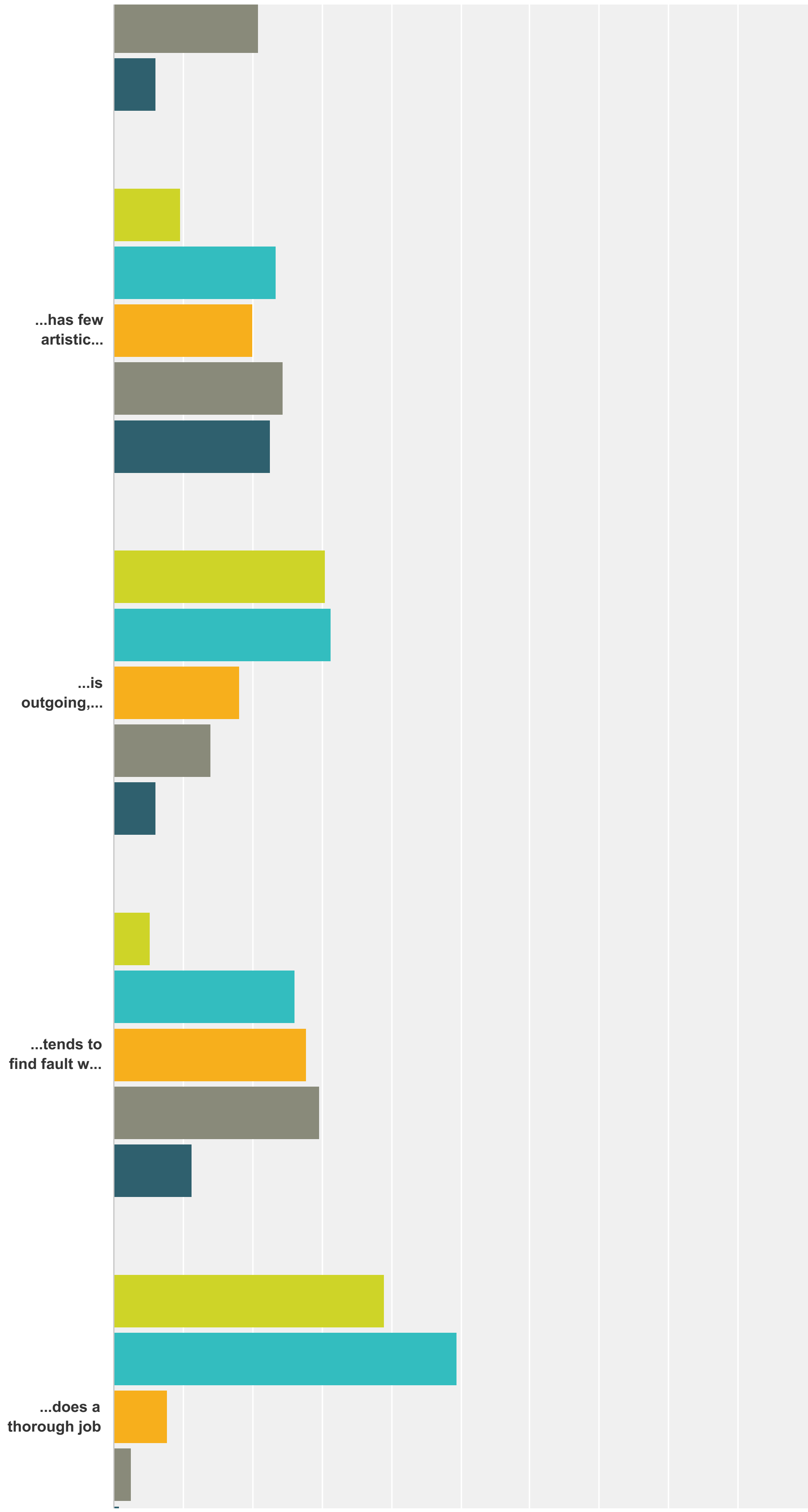
Q18 Are there any other media consumption activities that you & your different social groups take part in, in private settings like the home, that haven't been mentioned thus far?

Answered: 30 Skipped: 142

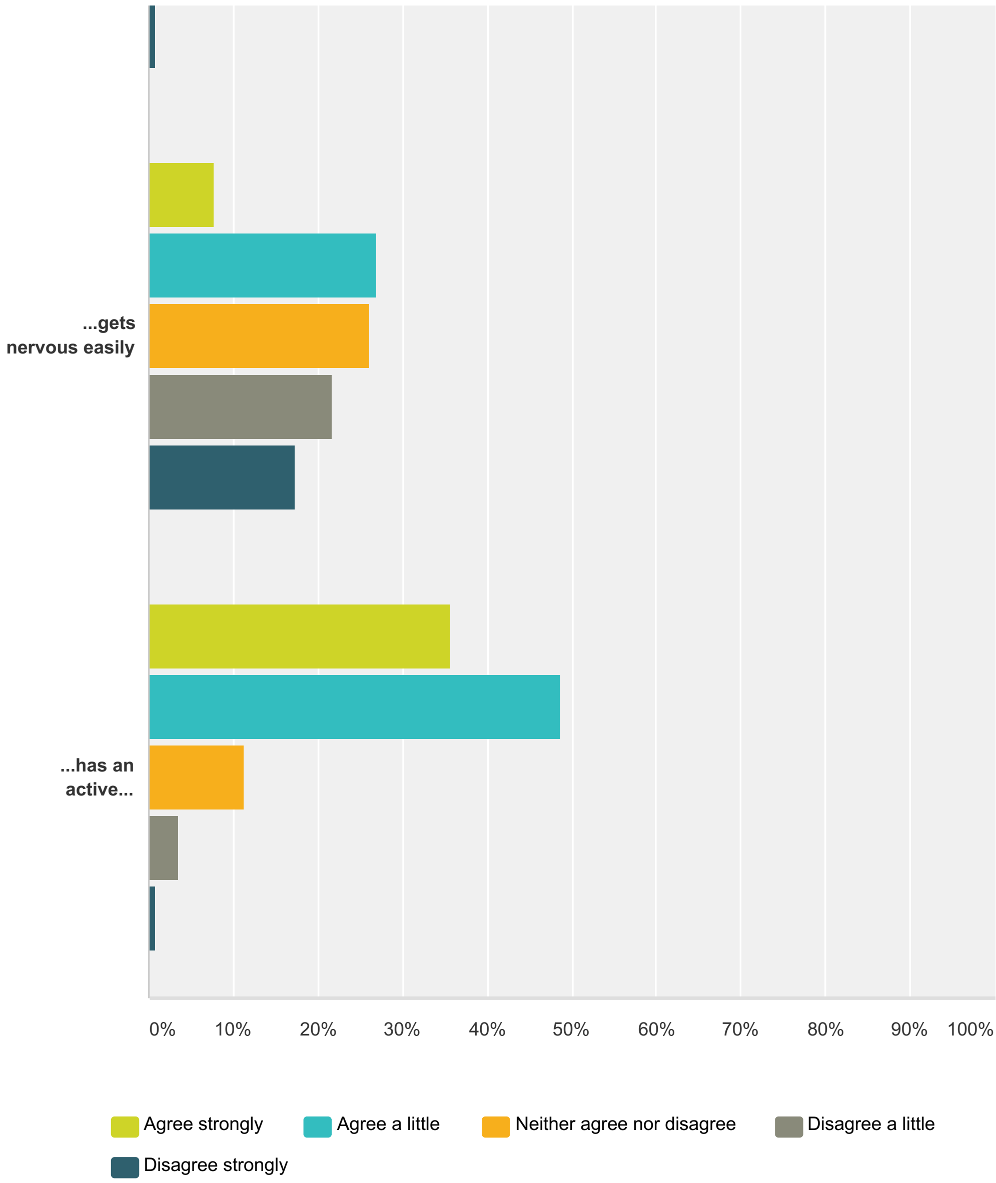
Q19 How well do the following statements describe your personality? "I see myself as someone who..."

Answered: 116 Skipped: 56




...has few
artistic...
...is
outgoing,...
...tends to
find fault w...
...does a
thorough job

Media Consumption Survey



	Agree strongly	Agree a little	Neither agree nor disagree	Disagree a little	Disagree strongly	Total
...is reserved	**16.67%** 19	**38.60%** 44	**17.54%** 20	**19.30%** 22	**7.89%** 9	114
...is generally trusting	**35.40%** 40	**37.17%** 42	**15.93%** 18	**6.19%** 7	**5.31%** 6	113
...tends to be lazy	**12.17%** 14	**29.57%** 34	**14.78%** 17	**22.61%** 26	**20.87%** 24	115
...is relaxed, handles stress well	**22.61%** 26	**33.04%** 38	**17.39%** 20	**20.87%** 24	**6.09%** 7	115
...has few artistic interests	**9.57%** 11	**23.48%** 27	**20.00%** 23	**24.35%** 28	**22.61%** 26	115
...is outgoing, sociable	**30.43%** 35	**31.30%** 36	**18.26%** 21	**13.91%** 16	**6.09%** 7	115
...tends to find fault with others	**5.22%** 6	**26.09%** 30	**27.83%** 32	**29.57%** 34	**11.30%** 13	115

...does a thorough job	**39.13%** 45	**49.57%** 57	**7.83%** 9	**2.61%** 3	**0.87%** 1	115
...gets nervous easily	**7.83%** 9	**26.96%** 31	**26.09%** 30	**21.74%** 25	**17.39%** 20	115
...has an active imagination	**35.65%** 41	**48.70%** 56	**11.30%** 13	**3.48%** 4	**0.87%** 1	115

Q20 (Optional) Contact information. If you are interested in participating in our future research, please complete these fields.

Answered: 23 Skipped: 149

Answer Choices	Responses	
Name:	91.30%	21
Company:	0.00%	0
Address 1:	0.00%	0
Address 2:	0.00%	0
City/Town:	0.00%	0
State/Province:	0.00%	0
ZIP/Postal Code:	0.00%	0
Country:	100.00%	23
Email Address:	82.61%	19
Phone Number:	0.00%	0

Q21 Any additional comments or feedback?

Answered: 11 Skipped: 161

D. Experiment 1 Materials

Participants in Experiment 1 (Chapter 3) were asked the following questions:

TLX Mental Demand How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?

TLX Physical Demand How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

TLX Temporal Demand How much time pressure did you feel due to the rate of pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

TLX-Performance How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

TLX-Effort How hard did you have to work (mentally and physically) to accomplish your level of performance?

TLX-Frustration How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

SUS-1 I think that i would like to use this method of control frequently

SUS-2 I found this method of control unnecessarily complex

SUS-3 I thought the method of control was easy to use

SUS-4 I think i would need the support of a technical person to be able to use this method of control

SUS-5 I found the various functions for handling control of this system fit together well

SUS-6 I thought there was too much inconsistency with this method of control

SUS-7 I would imagine that most people would learn to use this method of control very quickly

SUS-8 I found the method of control very cumbersome to use

SUS-9 I felt very confident using this method of control

SUS-10 I needed to learn a lot of things before i could get going with this method of control

I felt in control whilst using the system to perform the task

I felt the system was fair

This system gave me an efficient way to perform the task

I was satisfied with my experience using the system to accomplish my task

I was comfortable using the system

I was comfortable using the system with others

I would be comfortable using this system with friends

I would be comfortable using this system with family

How acceptable did you find this as a means of sharing control of a media system (e.g. tv, set top box) with others?

The plain language statement given to participants follows.

Plain Language Statement

1. Study title and Researcher Details

Mediation of Control (School of Computing Science)

Researcher: Mark McGill m.mcgill.1@research.gla.ac.uk (PhD Student 0303456)
Supervisor: Professor Stephen Brewster Stephen.Brewster@glasgow.ac.uk

2. Invitation paragraph

You are being invited to take part in a paid study, which should take approximately 1 hour to complete. Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Take time to decide whether or not you wish to take part.

If there is anything that is unclear, or you would like more information, or you have any questions, please feel free to raise these concerns with the researcher present. If you wish to discuss any aspect of this study at a later date, contact us at the email addresses listed above. Alternatively, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at the following email address: m.grosbras@psy.gla.ac.uk

3. What is the purpose of the study?

The purpose of this study is to investigate the different ways in which a group of people might control a shared media resource, like a television. Specifically, we are looking at what happens when multiple people have remote controls that control said resource, and the different ways we could decide which of the remote controls is in charge at any one time.

4. Why have I been chosen?

Your participation has been solicited through emails or notice board postings to which you replied.

5. Do I have to take part?

Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

6. What will happen to me if I take part?

You will be asked to perform a series of tasks in a small group, where each of you is using a supplied mobile smart phone device configured to act as a remote control for a TV display. Your actions with the phone device will be logged, and your physical actions will be recorded, both in terms of audio (vocal and non-vocal via a microphone in the room) and movement (video). You will then be debriefed and asked to answer some questions to help us better understand the acceptability of the experience you have undertaken.

7. Will my taking part in this study be kept confidential?

Yes, all data collected from you will be treated confidentially, will be seen in its raw form only by the experimenters, and if published will not be identifiable as coming from you.

8. What will happen to the results of the research study?

The results of the study may appear in a Doctoral thesis, and a number of published studies, again all in a confidential format where anonymity is preserved.

9. Who is organising and funding the research?

This project is part of an industrial studentship PhD part sponsored by Bang & Olufsen, being conducted at the University of Glasgow.

10. Who has reviewed the study?

This study adheres to the BPS ethical guidelines, and has been approved by the College of Science and Engineering ethics committee of The University of Glasgow (ref: CSE01184).

11. Contact for Further Information

Whilst you are free to discuss your participation in this study with the researcher, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at m.grosbras@psy.gla.ac.uk.

For further information, or if you wish to receive a summary of the findings of this experiment at a later date, please contact the researcher or the supervisor of this project, details listed below.

Researcher
Mark McGill
PhD Student 0303456
Email: m.mcgill.1@research.gla.ac.uk
Tel: 07791201325
Address: Room F122
17 Lilybank Gardens
Glasgow, G12 8RZ,
UK

Supervisor
Professor Stephen Brewster
Email: Stephen.Brewster@glasgow.ac.uk
Tel: +44 (0)141 330 4966

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Debrief

Thanks for taking part in the "mediation of control" experiment! If there are any questions or issues, or if you wish to receive a summary of the findings of this experiment at a later date, please say to the researcher now, or optionally contact the researcher or the supervisor of this project at a later date, details listed below.

Researcher
Mark McGill
PhD Student 0303456
Email: m.mcgill.1@research.gla.ac.uk
Tel: 07791201325
Address: Room F122
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Glasgow, G12 8RZ,
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Supervisor
Professor Stephen Brewster
Email: Stephen.Brewster@glasgow.ac.uk
Tel: +44 (0)141 330 4966

Whilst you are free to discuss your participation in this study with the researcher, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at m.grosbras@psy.gla.ac.uk.

Survey Sheet (after every condition)

Condition:

For the following questions, please answer on the basis of your experience with the control mechanism you have just encountered. Circle one response for each of the following items

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1. I felt in control whilst using the system to perform the task	1	2	3	4	5
2. I felt the system was fair	1	2	3	4	5
3. This system gave me an efficient way to perform the task	1	2	3	4	5
4. I was satisfied with my experience using the system to accomplish my task	1	2	3	4	5
5. I was comfortable using the system	1	2	3	4	5
6. I was comfortable using the system with others	1	2	3	4	5
7. I would be comfortable using this system with friends	1	2	3	4	5
8. I would be comfortable using this system with family	1	2	3	4	5
9. I can envisage situations in the future where this system would be useful to me	1	2	3	4	5

	Completely Unacceptable	Somewhat unacceptable	Neither acceptable nor unacceptable	Somewhat acceptable	Completely Acceptable
10. How acceptable did you find this as a means of controlling a media system?	1	2	3	4	5

Please read each question in turn and mark on the line where your response lies.

(If you are uncertain what the question is asking, refer to the descriptions at the bottom of the page)

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Mental Demand: How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Physical Demand: How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Temporal Demand: How much time pressure did you feel due to the rate of pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Performance: How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Frustration: How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

	Strongly Disagree				Strongly Agree
1. I think that I would like to use this method of control frequently	1	2	3	4	5
2. I found the method of control unnecessarily complex	1	2	3	4	5
3. I thought the method of control was easy to use	1	2	3	4	5
4. I think I would need the support of a technical person to be able to use this method of control	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency with this method of control	1	2	3	4	5
7. I would imagine that most people would learn to use this method of control very quickly	1	2	3	4	5
8. I found the method of control very cumbersome to use	1	2	3	4	5
9. I felt very confident using this method of control	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this method of control	1	2	3	4	5

Survey Sheet (on completion)

General information

Name:

Email Address:

Age: **Gender**: male / female

Relation to other two participants (tick all that apply)

Participant

□ Acquaintance □ Friend □ Brother/Sister □ Mother/Father □ Other family

□ Partner □ Cohabitant □ Lab/Project partner □ Spouse □ Work/University colleague

Participant

□ Acquaintance □ Friend □ Brother/Sister □ Mother/Father □ Other family

□ Partner □ Cohabitant □ Lab/Project partner □ Spouse □ Work/University colleague

What is your living status?

☐ Alone ☐ With Partner ☐ With Parents

☐ With Children ☐ With Flatmates

Other (please specify) ____

Please rank the control schemes you encountered

Label the top three 1, 2, or 3, depending on which you thought was the best (1), second best (2), or third best (3), then label the bottom three 8, 9, or 10, depending on which you thought was the worst (10), second worst (9), or third worst (8). Finally, rank those remaining (4, 5, 6, 7).

(if you are uncertain which description is which condition, please inform the demonstrator)

____ **a.** One person in control

____ **b.** One person in control with ability to lend control and take it back

____ **c.** One person in control, control can be passed around

____ **d.** One person in control, control can be taken off them

____ **e.** One person in control, turns taken

____ **f.** Everyone has control

____ **g.** Everyone has control, with majority rules voting for selections

____ **h.** Everyone has control, some people outrank others and can override their control

____ **i.** Everyone has a small bit of control

____ **j.** Everyone has control, can block other people temporarily

Circle one response for each of the following items

How well do the following statements describe your personality? "I see myself as someone who..."

	Agree Strongly	Agree a little	Neither agree nor disagree	Disagree a little	Disagree strongly
…is reserved	1	2	3	4	5
…is generally trusting	1	2	3	4	5
…tends to be lazy	1	2	3	4	5
…is relaxed, handles stress well	1	2	3	4	5
…has few artistic interests	1	2	3	4	5
…is outgoing, sociable	1	2	3	4	5
…tends to find fault with others	1	2	3	4	5
…does a thorough job	1	2	3	4	5
…gets nervous easily	1	2	3	4	5
…has an active imagination	1	2	3	4	5

E. EXPERIMENT 2 MATERIALS

Participants in Experiment 2 (Chapter 4) were asked the following questions:

TLX Mental Demand How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?

TLX Physical Demand How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

TLX Temporal Demand How much time pressure did you feel due to the rate of pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

TLX-Performance How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

TLX-Effort How hard did you have to work (mentally and physically) to accomplish your level of performance?

TLX-Frustration How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

SUS-1 I think that i would like to use this method of media browsing frequently

SUS-2 I found this method of media browsing unnecessarily complex

SUS-3 I thought the method of media browsing was easy to use

SUS-4 I think i would need the support of a technical person to be able to use this method of media browsing

SUS-5 I found the various functions for handling control of media browsing fit together well

SUS-6 I thought there was too much inconsistency with this method of media browsing

SUS-7 I would imagine that most people would learn to use this method of media browsing very quickly

SUS-8 I found the method of media browsing very cumbersome to use

SUS-9 I felt very confident using this method of media browsing

SUS-10 I needed to learn a lot of things before i could get going with this method of media browsing

WS-1 We were able to collaborate effectively

WS-2 We were able to work independently to complete the task

WS-3 It was easy to discuss the information we found

WS-4 We were able to work together to complete the task

WS-5 I was able to actively participate in completing the task

WE-1 The system was helpful in completing the given task

WE-2 I was aware of what my partner was doing

PE-1 My partner was aware of what I was doing

MO-1 How well did the system support collaboration?

MO-2 How well did the system support you to share particular information with your partner?

MO-3 I was able to tell when my partner was looking at what i was browsing

MO-4 How well did the system support you to see/review what your partner was talking about?

How acceptable did you find being able to hear audio coming from both displays?

How acceptable did you find being able to hear audio coming from both views?

How acceptable did you find wearing the 3d glasses?

The coloured eye adequately informed me when my partner was viewing the same screen as myself

The plain language statement given to participants follows.

Plain Language Statement

1. Study title and Researcher Details

Multiview Display Study (School of Computing Science)

Researcher: Mark McGill m.mcgill.1@research.gla.ac.uk (PhD Student 0303456)
Supervisor: Professor Stephen Brewster Stephen.Brewster@glasgow.ac.uk

IMPORTANT
In order to take part in this study, you must meet the following requirements:

1. Aged 18 or over
2. **No history** (personal and family) **of epileptic seizures, strokes, or photosensitivity**
3. **Not a member of any of the following groups**
    a. Pregnant women
    b. The elderly
    c. Sufferers of serious medical conditions
    d. Sleep deprived
    e. Under the influence of alcohol
    f. Sufferers of motion sickness
    g. Sufferers of visual disorders

If you experience any of the following symptoms during this study, stop viewing the multi-view display immediately and inform the researcher: (1) altered vision; (2) lightheadedness; (3) dizziness; (4) involuntary movements such as eye or muscle twitching; (5) confusion; (6) nausea; (7) loss of awareness; (8) convulsions; (9) cramps; and/ or (10) disorientation.

2. Invitation paragraph

You are being invited to take part in a paid study, which should take approximately 1 hour 15 minutes to complete. Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Take time to decide whether or not you wish to take part.

If there is anything that is unclear, or you would like more information, or you have any questions, please feel free to raise these concerns with the researcher present. If you wish to discuss any aspect of this study at a later date, contact us at the email addresses listed above. Alternatively, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at the following email address: Christoph.Scheepers@glasgow.ac.uk

3. What is the purpose of the study?

The purpose of this study is to investigate the potential for utilizing multi-view displays (displays that can provide unique views to every person in the room) for aiding group collaboration within tasks representative of those conducted in the home. For this study, we will be using a 24inch display paired with 3d glasses to enable multi-view use, and examining it's usage within a collaborative browsing task: picking what to watch on tv.

4. Why have I been chosen?

Your participation has been solicited through emails or notice board postings to which you replied.

5. Do I have to take part?

Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

6. What will happen to me if I take part?

You will be asked to perform a collaborative media browsing task in your pair, where each of you is using a supplied mobile phone as a remote control, and a pair of 3d glasses in order to enable multi-view. Your activity will be logged and recorded, both in terms of audio (vocal and non-vocal via a microphone in the room), movement (video), and interaction with the system. You will then be debriefed and asked to answer some questions to help us better understand the acceptability of the experience you have undertaken. For taking part, you will be paid £8.

7. Will my taking part in this study be kept confidential?

Yes, all data collected from you will be treated confidentially, will be seen in its raw form only by the experimenters, and if published will not be identifiable as coming from you. You will be reminded not to log in to any personalized web services on the devices provided whilst taking part in the experiment, as all content entered will be recorded.

8. What will happen to the results of the research study?

The results of the study may appear in a Doctoral thesis, and a number of published studies, again all in a confidential format where anonymity is preserved.

9. Who is organising and funding the research?

This project is part of an industrial studentship PhD part sponsored by Bang & Olufsen, being conducted at the University of Glasgow.

10. Who has reviewed the study?

This study adheres to the BPS ethical guidelines, and has been approved by the College of Science and Engineering ethics committee of The University of Glasgow (ref: CSE01349).

11. Contact for Further Information

Whilst you are free to discuss your participation in this study with the researcher, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at Christoph.Scheepers@glasgow.ac.uk

For further information, or if you wish to receive a summary of the findings of this experiment at a later date, please contact the researcher or the supervisor of this project, details listed below.

Researcher
Mark McGill
PhD Student 0303456
Email: m.mcgill.1@research.gla.ac.uk
Tel: 07791201325
Address: Room F122
17 Lilybank Gardens
Glasgow, G12 8RZ, UK

Supervisor
Professor Stephen Brewster
Email: Stephen.Brewster@glasgow.ac.uk
Tel: +44 (0)141 330 4966

University of Glasgow

Debrief

Thanks for taking part in the "multi-view display" experiment! If there are any questions or issues, or if you wish to receive a summary of the findings of this experiment at a later date, please say to the researcher now, or optionally contact the researcher or the supervisor of this project at a later date, details listed below.

Researcher
Mark McGill
PhD Student 0303456
Email: m.mcgill.1@research.gla.ac.uk
Tel: 07791201325
Address: Room F122
17 Lilybank Gardens
Glasgow, G12 8RZ,
UK

Supervisor
Professor Stephen Brewster
Email: Stephen.Brewster@glasgow.ac.uk
Tel: +44 (0)141 330 4966

Whilst you are free to discuss your participation in this study with the researcher, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at Christoph.Scheepers@glasgow.ac.uk

Survey Sheet (on completion)

General information

Name:

Email Address:

Age: **Gender**: male / female

I consent to being contacted for related follow up studies (tick if you agree): □

Relation to other participant (tick all that apply)

Participant

□ Acquaintance □ Friend □ Brother/Sister □ Mother/Father □ Other family

□ Partner □ Cohabitant □ Lab/Project partner □ Spouse □ Work/University colleague

What is your living status?

☐ Alone ☐ With Partner ☐ With Parents

☐ With Children ☐ With Flatmates

Other (please specify) ____

Please rank the schemes you encountered

Label them depending on which you thought was the best (1), second best (2), or third best (3).

(if you are uncertain which description is which condition, please inform the demonstrator)

____ **a.** Single display (single view)

____ **b.** Two displays (two views)

____ **c.** Multiview (3d glasses, two views)

F. EXPERIMENT 3 MATERIALS

Participants in Experiment 3 (Chapter 4) were asked the following questions:

TLX Mental Demand How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?

TLX Physical Demand How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

TLX Temporal Demand How much time pressure did you feel due to the rate of pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

TLX-Performance How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

TLX-Effort How hard did you have to work (mentally and physically) to accomplish your level of performance?

TLX-Frustration How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

SUS-1 I think that i would like to use this method of media browsing frequently

SUS-2 I found this method of media browsing unnecessarily complex

SUS-3 I thought the method of media browsing was easy to use

SUS-4 I think i would need the support of a technical person to be able to use this method of media browsing

SUS-5 I found the various functions for handling control of media browsing fit together well

SUS-6 I thought there was too much inconsistency with this method of media browsing

SUS-7 I would imagine that most people would learn to use this method of media browsing very quickly

SUS-8 I found the method of media browsing very cumbersome to use

SUS-9 I felt very confident using this method of media browsing

SUS-10 I needed to learn a lot of things before i could get going with this method of media browsing

WS-1 We were able to collaborate effectively

WS-2 We were able to work independently to complete the task

WS-3 It was easy to discuss the information we found

WS-4 We were able to work together to complete the task

WS-5 I was able to actively participate in completing the task

WE-1 The system was helpful in completing the given task

WE-2 I was aware of what my partner was doing

PE-1 My partner was aware of what I was doing

DIST-1 I found my partners activity distracting

DIST-2 I felt I could control how aware I was of my partners activity

MO-1 How well did the system support collaboration?

MO-2 How well did the system support you to share particular information with your partner?

MO-3 I was able to tell when my partner was looking at what i was browsing

MO-4 How well did the system support you to see/review what your partner was talking about?

The plain language statement given to participants follows.

Plain Language Statement

1. Study title and Researcher Details

Multiview Display Study 2 (School of Computing Science)

Researcher: Mark McGill m.mcgill.1@research.gla.ac.uk (PhD Student 0303456)
Supervisor: Professor Stephen Brewster Stephen.Brewster@glasgow.ac.uk

IMPORTANT
In order to take part in this study, you must meet the following requirements:

1. Aged 18 or over
2. **No history** (personal and family) **of epileptic seizures, strokes, or photosensitivity**
3. **Not a member of any of the following groups**
    a. Pregnant women
    b. The elderly
    c. Sufferers of serious medical conditions
    d. Sleep deprived
    e. Under the influence of alcohol
    f. Sufferers of motion sickness
    g. Sufferers of visual disorders

If you experience any of the following symptoms during this study, stop viewing the multi-view display immediately and inform the researcher: (1) altered vision; (2) lightheadedness; (3) dizziness; (4) involuntary movements such as eye or muscle twitching; (5) confusion; (6) nausea; (7) loss of awareness; (8) convulsions; (9) cramps; and/ or (10) disorientation.

2. Invitation paragraph

You are being invited to take part in a paid study, which should take approximately 1 hour to complete. Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Take time to decide whether or not you wish to take part.

If there is anything that is unclear, or you would like more information, or you have any questions, please feel free to raise these concerns with the researcher present. If you wish to discuss any aspect of this study at a later date, contact us at the email addresses listed above. Alternatively, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at the following email address: Christoph.Scheepers@glasgow.ac.uk

3. What is the purpose of the study?

The purpose of this study is to investigate the potential for utilizing multi-view displays (displays that can provide unique views to every person in the room) for aiding group collaboration within tasks representative of those conducted in the home. For this study, we will be using a 24inch display paired with 3d glasses to enable multi-view use, and examining it's usage within a collaborative browsing task: picking films to watch together.

4. Why have I been chosen?

Your participation has been solicited through emails or notice board postings to which you replied.

5. Do I have to take part?

Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

6. What will happen to me if I take part?

You will be asked to perform a collaborative media browsing task in your pair, where each of you is using a supplied mobile phone as a remote control, and a pair of 3d glasses in order to enable multi-view. Your activity will be logged and recorded, both in terms of audio (vocal and non-vocal via a microphone in the room), movement (video), and interaction with the system. You will then be debriefed and asked to answer some questions to help us better understand the acceptability of the experience you have undertaken. For taking part, you will be paid £6.

7. Will my taking part in this study be kept confidential?

Yes, all data collected from you will be treated confidentially, will be seen in its raw form only by the experimenters, and if published will not be identifiable as coming from you. You will be reminded not to log in to any personalized web services on the devices provided whilst taking part in the experiment, as all content entered will be recorded.

8. What will happen to the results of the research study?

The results of the study may appear in a Doctoral thesis, and a number of published studies, again all in a confidential format where anonymity is preserved.

9. Who is organising and funding the research?

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10. Who has reviewed the study?

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Glasgow, G12 8RZ, UK

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Tel: +44 (0)141 330 4966

Debrief

Thanks for taking part in the "multi-view display" experiment! If there are any questions or issues, or if you wish to receive a summary of the findings of this experiment at a later date, please say to the researcher now, or optionally contact the researcher or the supervisor of this project at a later date, details listed below.

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Whilst you are free to discuss your participation in this study with the researcher, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at Christoph.Scheepers@glasgow.ac.uk

Survey Sheet (on completion)

General information

Name:

Email Address:

Age: **Gender**: male / female

I consent to being contacted for related follow up studies (tick if you agree): □

Relation to other participant (tick all that apply)

Participant

□ Acquaintance □ Friend □ Brother/Sister □ Mother/Father □ Other family

□ Partner □ Cohabitant □ Lab/Project partner □ Spouse □ Work/University colleague

Please rank the schemes you encountered

Label them depending on which you thought was the best (1), second best (2), or third best (3).

(if you are uncertain which description is which condition, please inform the demonstrator)

____ **a.** "Fullscreen" multiview tv, with taps to switch displays, long press to peek

____ **b.** "Overview" multiview tv, with a slider for setting how much of the display is used for an overview of both views

____ **c.** "Fullscreen+ Overview" multiview tv, with the ability to switch between being zoomed in on one view, and the overview mode where you can see both views, using a three finger tap

G. EXPERIMENT 4 MATERIALS

Participants in Experiment 4 (Chapter 5) were asked the following questions:

TLX Mental Demand How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?

TLX Physical Demand How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

TLX Temporal Demand How much time pressure did you feel due to the rate of pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

TLX-Performance How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

TLX-Effort How hard did you have to work (mentally and physically) to accomplish your level of performance?

TLX-Frustration How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

SUS-1 I think that i would like to use this method of sharing use of the screen frequently

SUS-2 I found this method of sharing use of the screen unnecessarily complex

SUS-3 I thought the method of sharing use of the screen was easy to use

SUS-4 I think i would need the support of a technical person to be able to use this method of sharing use of the screen

SUS-5 I found the various functions for handling control of sharing use of the screen fit together well

SUS-6 I thought there was too much inconsistency with this method of sharing use of the screen

SUS-7 I would imagine that most people would learn to use this method of sharing use of the screen very quickly

SUS-8 I found the method of sharing use of the screen very cumbersome to use

SUS-9 I felt very confident using this method of sharing use of the screen

SUS-10 I needed to learn a lot of things before i could get going with this method of sharing use of the screen

WS-1 We were able to collaborate effectively

WS-2 We were able to work independently to complete the task

WS-3 It was easy to discuss the information we found

WS-4 We were able to work together to complete the task

WS-5 I was able to actively participate in completing the task

MO-1 How well did the system support collaboration?

MO-2-Particular User How well did the system support you to share particular information with a particular user in the group?

MO-2-Everyone How well did the system support you to share particular information with everyone in the group?

MO-2-See/review How well did the system support you to see/review what the other users were talking about?

WE-1 The system was helpful in completing the given task

WE-2 I was aware of what other users were doing

ME-1 I would be comfortable using this system with friends

ME-2 I would be comfortable using this system with family

ME-3 I would use this system in my home

ME-4 I would have privacy concerns if using this system with others

ME-5 How acceptable did you find requesting use of the display/passing the display?

ME-6 How acceptable did you find taking the display from whomever currently possessed it?

ME-7 How intrusive did you find the permanent buttons on the screen for managing the display?

ME-8 I found the colour based glow around the screen adequately helped me determine if i currently owned the display

ME-9 I found the colour based glow around the screen adequately helped me determine who owned the display

ME-10 I felt adequately notified when someone requested the display from me

PE-1 My partner was aware of what I was doing

DIST-1 I found my partners activity distracting

DIST-2 I felt I could control how aware I was of my partners activity

The plain language statement given to participants follows.

Plain Language Statement

1. Study title and Researcher Details

Multi-User Screen Sharing (School of Computing Science)

Researcher: Mark McGill m.mcgill.1@research.gla.ac.uk (PhD Student 0303456)
Supervisor: Professor Stephen Brewster Stephen.Brewster@glasgow.ac.uk

2. Invitation paragraph

You are being invited to take part in a paid study, which should take approximately 1 hour 15 minutes to complete. Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Take time to decide whether or not you wish to take part.

If there is anything that is unclear, or you would like more information, or you have any questions, please feel free to raise these concerns with the researcher present. If you wish to discuss any aspect of this study at a later date, contact us at the email addresses listed above. Alternatively, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at the following email address: Christoph.Scheepers@glasgow.ac.uk

3. What is the purpose of the study?

The purpose of this study is to investigate the potential for screen mirroring for aiding group collaboration. Screen mirroring refers to showing the content on a device (e.g. phone/tablet) on a larger, shared display. For this study, we will be facilitating shared screen mirroring, where management as to who is currently using the display is conducted by the group in a self-organised fashion.

4. Why have I been chosen?

Your participation has been solicited through emails or notice board postings to which you replied.

5. Do I have to take part?

Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

6. What will happen to me if I take part?

You will be asked to perform a series of tasks (planning trips) in a small group, where each of you is using a supplied mobile smart phone device with internet connectivity. Your actions with the phone device will be logged and recorded, as will your physical actions, both in terms of audio (vocal and non-vocal via a microphone in the room) and movement (video). You will then be debriefed and asked to answer some questions to help us better understand the acceptability of the experience you have undertaken. For taking part, you will be paid £8.

7. Will my taking part in this study be kept confidential?

Yes, all data collected from you will be treated confidentially, will be seen in its raw form only by the experimenters, and if published will not be identifiable as coming from you. You will be reminded not to log in to any personalized web services on the devices provided whilst taking part in the experiment, as all content entered will be recorded.

8. What will happen to the results of the research study?

The results of the study may appear in a Doctoral thesis, and a number of published studies, again all in a confidential format where anonymity is preserved.

9. Who is organising and funding the research?

This project is part of an industrial studentship PhD part sponsored by Bang & Olufsen, being conducted at the University of Glasgow.

10. Who has reviewed the study?

This study adheres to the BPS ethical guidelines, and has been approved by the College of Science and Engineering ethics committee of The University of Glasgow (ref: CSE01285).

11. Contact for Further Information

Whilst you are free to discuss your participation in this study with the researcher, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at Christoph.Scheepers@glasgow.ac.uk

For further information, or if you wish to receive a summary of the findings of this experiment at a later date, please contact the researcher or the supervisor of this project, details listed below.

Researcher
Mark McGill
PhD Student 0303456
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Tel: 07791201325
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Glasgow, G12 8RZ,
UK

Supervisor
Professor Stephen Brewster
Email: Stephen.Brewster@glasgow.ac.uk
Tel: +44 (0)141 330 4966

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Debrief

Thanks for taking part in the "multi-user screen sharing" experiment! If there are any questions or issues, or if you wish to receive a summary of the findings of this experiment at a later date, please say to the researcher now, or optionally contact the researcher or the supervisor of this project at a later date, details listed below.

Researcher
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PhD Student 0303456
Email: m.mcgill.1@research.gla.ac.uk
Tel: 07791201325
Address: Room F122
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Whilst you are free to discuss your participation in this study with the researcher, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at Christoph.Scheepers@glasgow.ac.uk

University of Glasgow

Survey Sheet (on completion)

General information

Name:

Email Address:

Age: **Gender**: male / female

I consent to being contacted for related follow up studies (tick if you agree): □

Relation to other two participants (tick all that apply)

Participant

□ Acquaintance □ Friend □ Brother/Sister □ Mother/Father □ Other family

□ Partner □ Cohabitant □ Lab/Project partner □ Spouse □ Work/University colleague

Participant

□ Acquaintance □ Friend □ Brother/Sister □ Mother/Father □ Other family

□ Partner □ Cohabitant □ Lab/Project partner □ Spouse □ Work/University colleague

What is your living status?

☐ Alone ☐ With Partner ☐ With Parents

☐ With Children ☐ With Flatmates

Other (please specify) ____

Have you ever used screen-mirroring for mobile devices before? If so, tick which technologies you have used:

☐ Apple Airplay ☐ Samsung Allshare-cast ☐ Miracast

☐ Cable from phone ☐ Other

If other, please specify:____

Please rank the schemes you encountered

Label them depending on which you thought was the best (1), second best (2), or third best (3).

(if you are uncertain which description is which condition, please inform the demonstrator)

____ **a.** Everyone has a device

____ **b.** Everyone has a device, one device is permanently mirrored

____ **c.** Everyone has a device and every device can be mirrored

Circle one response for each of the following items

How well do the following statements describe your personality? "I see myself as someone who..."

	Agree Strongly	**Agree a little**	**Neither agree nor disagree**	**Disagree a little**	**Disagree strongly**
…is reserved	1	2	3	4	5
…is generally trusting	1	2	3	4	5
…tends to be lazy	1	2	3	4	5
…is relaxed, handles stress well	1	2	3	4	5
…has few artistic interests	1	2	3	4	5
…is outgoing, sociable	1	2	3	4	5
…tends to find fault with others	1	2	3	4	5
…does a thorough job	1	2	3	4	5
…gets nervous easily	1	2	3	4	5
…has an active imagination	1	2	3	4	5

Finally, please tick the box that best represents your level of usage with respect to mobile browsing:

Never	Monthly	Weekly	Daily	All the time

H. EXPERIMENT 5 MATERIALS

Participants in Experiment 5 (Chapter 5) were asked the following questions:

TLX Mental Demand How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?

TLX Physical Demand How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

TLX Temporal Demand How much time pressure did you feel due to the rate of pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

TLX-Performance How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

TLX-Effort How hard did you have to work (mentally and physically) to accomplish your level of performance?

TLX-Frustration How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

WS-1 We were able to collaborate effectively

WS-2 We were able to work independently to complete the task

WS-3 It was easy to discuss the information we found

WS-4 We were able to work together to complete the task

WS-5 I was able to actively participate in completing the task

SUS-1 I think that I would like to use this type of TV frequently

SUS-2 I found this TV unnecessarily complex

SUS-3 I thought the TV was easy to use

SUS-4 I think i would need the support of a technical person to be able to use this TV

SUS-5 I found the various functions for handling control of the TV fit together well

SUS-6 I thought there was too much inconsistency with this TV

SUS-7 I would imagine that most people would learn to use this TV very quickly

SUS-8 I found the TV very cumbersome to use

SUS-9 I felt very confident using this TV

SUS-10 I needed to learn a lot of things before i could get going with this TV

WE-2 I was aware of what my partner was doing

How well did the system support viewing the TV content

How well did the system support viewing device activity?

How satisfied were you with your capability to listen to the TV and the devices being mirrored?

I found the TV to be distracting

The plain language statement given to participants follows.

University of Glasgow

Plain Language Statement

1. Study title and Researcher Details

Multi-user Multi-view Screen Mirroring Study (School of Computing Science)

Researcher: Mark McGill m.mcgill.1@research.gla.ac.uk (PhD Student 0303456)
Supervisor: Professor Stephen Brewster Stephen.Brewster@glasgow.ac.uk

IMPORTANT
In order to take part in this study, you must meet the following requirements:

1. Aged 18 or over
2. **No history** (personal and family) **of epileptic seizures, strokes, or photosensitivity**
3. **Not a member of any of the following groups**
    a. Pregnant women
    b. The elderly
    c. Sufferers of serious medical conditions
    d. Sleep deprived
    e. Under the influence of alcohol
    f. Sufferers of motion sickness
    g. Sufferers of visual disorders

If you experience any of the following symptoms during this study, stop viewing the multi-view display immediately and inform the researcher: (1) altered vision; (2) lightheadedness; (3) dizziness; (4) involuntary movements such as eye or muscle twitching; (5) confusion; (6) nausea; (7) loss of awareness; (8) convulsions; (9) cramps; and/ or (10) disorientation.

2. Invitation paragraph

You are being invited to take part in a paid study, which should take approximately 1 hour 20 minutes to complete. Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Take time to decide whether or not you wish to take part.

If there is anything that is unclear, or you would like more information, or you have any questions, please feel free to raise these concerns with the researcher present. If you wish to discuss any aspect of this study at a later date, contact us at the email addresses listed above. Alternatively, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at the following email address: Christoph.Scheepers@glasgow.ac.uk

3. What is the purpose of the study?

The purpose of this study is to investigate the potential for screen mirroring for aiding group collaboration within tasks representative of those conducted in the home. Screen mirroring refers to showing the content on a device (e.g. phone/tablet) on a larger, shared display. For this study, we will be using smartphone devices whose displays can be mirrored onto a TV display. This TV display is also capable of multi-view usage, meaning that when you are wearing given 3D glasses you will be able to perceive a completely independent and separate view to your partner. We will be examining screen mirroring usage within a collaborative browsing task: picking what movies to watch together.

4. Why have I been chosen?

Your participation has been solicited through emails or notice board postings to which you replied.

5. Do I have to take part?

Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

6. What will happen to me if I take part?

You will be asked to perform a collaborative media browsing task in your pair, where each of you is using a supplied mobile phone, and a pair of 3d glasses in order to enable multi-view (where required). Your activity will be logged and recorded, both in terms of audio (vocal and non-vocal via a microphone in the room), movement and speech (video), and interaction with the system. You will then be debriefed and asked to answer some questions to help us better understand the acceptability of the experience you have undertaken. For taking part, you will be paid £10.

7. Will my taking part in this study be kept confidential?

Yes, all data collected from you will be treated confidentially, will be seen in its raw form only by the experimenters, and if published will not be identifiable as coming from you. You will be reminded not to log in to any personalized web services on the devices provided whilst taking part in the experiment, as all content entered will be recorded.

8. What will happen to the results of the research study?

The results of the study may appear in a Doctoral thesis, and a number of published studies, again all in a confidential format where anonymity is preserved.

9. Who is organising and funding the research?

This project is part of an industrial studentship PhD part sponsored by Bang & Olufsen, being conducted at the University of Glasgow.

10. Who has reviewed the study?

This study adheres to the BPS ethical guidelines, and has been approved by the College of Science and Engineering ethics committee of The University of Glasgow (ref: 300140045).

11. Contact for Further Information

Whilst you are free to discuss your participation in this study with the researcher, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at Christoph.Scheepers@glasgow.ac.uk

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17 Lilybank Gardens
Glasgow, G12 8RZ, UK

Supervisor
Professor Stephen Brewster
Email: Stephen.Brewster@glasgow.ac.uk
Tel: +44 (0)141 330 4966

University of Glasgow

Debrief

Thanks for taking part in the "multi-user multi-view screen mirroring" experiment! If there are any questions or issues, or if you wish to receive a summary of the findings of this experiment at a later date, please say to the researcher now, or optionally contact the researcher or the supervisor of this project at a later date, details listed below.

Researcher
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Whilst you are free to discuss your participation in this study with the researcher, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at Christoph.Scheepers@glasgow.ac.uk

University of Glasgow

Survey Sheet (on completion)

General information

Name:

Email Address:

Age: **Gender**: male / female

I consent to being contacted for related follow up studies (tick if you agree): □

Do you have any privacy concerns regarding mirroring devices e.g. personal phone, tablet etc. to a shared TV?

____

____

____

____

____

For each of the devices and mirroring behaviours below, please rate how socially acceptable you find the given screen mirroring technique:

Personal devices (e.g. your phone) where…	**Very Unacceptable**	**Unacceptable**	**Neutral**	**Acceptable**	**Very Acceptable**
The user of the device chooses when, and for how long, to mirror the device to a TV					
The user of the device chooses to make the device available and accessible to others in the home to view on-demand on the TV for a period of time					
Others in the home can view the device on-demand at any time					

Shared devices (e.g. family tablet) where…	**Very Unacceptable**	**Unacceptable**	**Neutral**	**Acceptable**	**Very Acceptable**
The user of the device chooses when, and for how long, to mirror the device to a TV					
The user of the device chooses to make the device available and accessible to others in the home to view on-demand on the TV for a period of time					
Others in the home can view the device on-demand at any time					

If privacy concerns could be alleviated (e.g. through hiding notifications, only sharing certain app activity etc.), for each of the devices and mirroring behaviours below, please rate how socially acceptable you find this form of mirroring:

Personal devices (e.g. your phone) where…	**Very Unacceptable**	**Unacceptable**	**Neutral**	**Acceptable**	**Very Acceptable**
The user of the device chooses when, and for how long, to mirror the device to a TV					
The user of the device chooses to make the device available and accessible to others in the home to view on-demand on the TV for a period of time					
Others in the home can view the device on-demand at any time					

Shared devices (e.g. family tablet) where…	**Very Unacceptable**	**Unacceptable**	**Neutral**	**Acceptable**	**Very Acceptable**
The user of the device chooses when, and for how long, to mirror the device to a TV					
The user of the device chooses to make the device available and accessible to others in the home to view on-demand on the TV for a period of time					
Others in the home can view the device on-demand at any time					

Please rank the systems you have trialled today

Label them from best (1) to worst (4).

(if you are uncertain which description is which condition, please inform the demonstrator)

____ **a.** Full-screen sharing of the display with ability to take display

____ **b.** Split-screen sharing of the display

____ **c.** Split-screen sharing of the display, with automatic full-screen of a mirrored device when video was playing

____ **d.** Multi-view (independent views using glasses) where each user controls their own view

I. EXPERIMENT 6 MATERIALS

Three questionnaires were delivered to CastAway participants (Chapter 6): the pre-questionnaire (at start of study), the connectedness questionnaire (during study) and the post questionnaire (at end of study), contained in this appendix. The plain language statement and user manual given to participants follow.

Pre-study questionnaire

Thanks for choosing to take part in this study! You'll be filling out a few of these questionnaires over the course of the week, so please make sure to enter the same name and group so i know who is who! Thanks again!

*Required

1. **Name** *

   ....

2. **Group** *

   Mark only one oval.

   ( ) A
   ( ) B
   ( ) C
   ( ) D
   ( ) E
   ( ) F
   ( ) G
   ( ) H
   ( ) I
   ( ) J

3. **Email** *

   ....

4. **Age** *

   ....

5. **Gender** *

   Mark only one oval.

   ( ) Male
   ( ) Female
   ( ) Other: ....

6. **Distance between you and your partner (approximately, in Miles)?** *

   ....

7. **How long have you been at-a-distance from your partner in this study (in months)?**

8. **How do you typically communicate with your partner (tick all that apply)?** *
Tick all that apply.
   - [ ] text messaging
   - [ ] phone calls
   - [ ] email
   - [ ] social network sites (i.e. facebook)
   - [ ] instant messages/chat
   - [ ] video chat (i.e. skype)
   - [ ] blog
   - [ ] twitter
   - [ ] Other:

9. **How often do you communicate with your partner at a distance?** *
Mark only one oval.
   - Daily
   - 3-4 times per week
   - 3-4 times per month
   - One per month
   - 5-10 times per year
   - 1-4 times per year
   - Never

10. **How often do you see your partner in person?** *
Mark only one oval.
   - Daily
   - 3-4 times per week
   - 3-4 times per month
   - One per month
   - 5-10 times per year
   - 1-4 times per year
   - Never

Synchronous media consumption

11. **How often do you consume long videos (e.g. films, tv) synchronously together?** *
Mark only one oval.

- Daily
- 3-4 times per week
- 3-4 times per month
- One per month
- 5-10 times per year
- 1-4 times per year
- Never

12. **How often do you consume short videos (e.g. youtube) synchronously together?** *
Mark only one oval.

- Daily
- 3-4 times per week
- 3-4 times per month
- One per month
- 5-10 times per year
- 1-4 times per year
- Never

13. **How often do you consume music (e.g. a shared playlist, same radio station etc.) synchronously together?** *
Mark only one oval.

- Daily
- 3-4 times per week
- 3-4 times per month
- One per month
- 5-10 times per year
- 1-4 times per year
- Never

14. **How often do you play games synchronously together?** *
Mark only one oval.

- Daily
- 3-4 times per week
- 3-4 times per month
- One per month
- 5-10 times per year
- 1-4 times per year
- Never

15. **How often do you consume webcontent (e.g. images from imgur, links from reddit etc.) synchronously together?** *
Mark only one oval.

- Daily
- 3-4 times per week
- 3-4 times per month
- One per month
- 5-10 times per year
- 1-4 times per year
- Never

Synchronous media consumption cont...

16. **How satisfied are you with the use of technology in your relationship?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Not at all satisfied								Very satisfied

17. **How much do you miss watching long videos (e.g. TV, films) together in person?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Not at all								Very much

18. **Do you think it would be worthwhile having a system to allow you to watch long videos (e.g. TV, films) together at a distance?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Not at all								Very much

19. **How much do you miss watching short videos (e.g. youtube) together in person?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Not at all								Very much

20. **Do you think it would be worthwhile having a system to allow you to watch short videos (e.g. youtube) together at a distance?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Not at all	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very much

21. **How much do you miss listening to music/radio together in person?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Not at all	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very much

22. **Do you think it would be worthwhile having a system to allow you to listen to music/radio together at a distance?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Not at all	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very much

23. **How much do you miss playing games together in person?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Not at all	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very much

24. **Do you think it would be worthwhile having a system to allow you to play games together at a distance?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Not at all	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very much

25. **How much do you miss browsing web content (e.g. imgur, reddit) together in person?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Not at all	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very much

26. **Do you think it would be worthwhile having a system to allow you to browse web content together at a distance?** *

Mark only one oval.

	1	2	3	4	5	6	7	
Not at all								Very much

Connectedness questionnaire

This should be filled out three times by participants.

The first time should be at the start of the study. You will both use the communications facilities provided by our system to communicate for at least 10 minutes, using the text, audio, and video chat functions however you would prefer. Once you are done communicating with your partner, fill this form out.

The second and third times will be after you have used our CastAway app for music consumption, and TV consumption.Fill out the form for music and for TV seperately. We'd ask that you don't fill the forms out until you have used each system at least once, and preferably on your last anticipated usage, and that you fill the form out immediately after using the TV or music functionality.

Thanks!

*Required

1. **Name** *

   ....

2. **Group** *

   Mark only one oval.

   ⬭ A
   ⬭ B
   ⬭ C
   ⬭ D
   ⬭ E
   ⬭ F
   ⬭ G
   ⬭ H
   ⬭ I
   ⬭ J

3. **Which questionnaire is this:** *

   Mark only one oval.

   ⬭ Start of study, communications only *Skip to question 4.*
   ⬭ Synchronous TV (after at least one use) *Skip to question 6.*
   ⬭ Synchronous music (after at least one use) *Skip to question 5.*

Closeness (communications)

4. **Using the devices to communicate together made me feel closer to my remote companion.**
   Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

Skip to question 7.

Closeness (music)

5. **Listening to music together remotely made me feel closer to my remote companion.**
   Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

Skip to question 7.

Closeness (TV)

6. **Watching TV together remotely made me feel closer to my remote companion.**
   Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

Skip to question 7.

Affective benefits and costs of communication technologies

For these questions, the word "technology" refers to whichever system you selected in the previous question, one of:

Start of study, communications only
Synchronous TV with communications
Synchronous music with communications

7. **Communicating with my partner using technology helps me tell how my partner is feeling that day** *
Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

8. **Communicating with my partner using technology helps me let my partner know how i am feeling** *
Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

9. **Communicating with my partner using technology helps me see how much my partner cares about me** *
Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

10. **I feel that contact with me using technology is engaging for my partner** *
Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

11. **I am excited about using technology with my partner** *
Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

12. **I have fun with my partner when using technology** *

Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

13. **Communicating with my partner using technology helps me feel closer to my partner** *

Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

Affective benefits page 2

For these questions, the word "technology" refers to whichever system you selected in the previous question, one of:

Start of study, communications only
Synchronous TV with communications
Synchronous music with communications

14. **After we are done communicating, I still keep thinking back to something my partner shared using technology** *

Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

15. **Communicating with my partner using technology helps me feel more connected to my partner** *

Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

16. **Communicating with my partner using technology helps me provide my partner with social support.** *

Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

17. **My partner makes me feel special in our contact using technology.** *

Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

18. **Communicating with me using technology helps my partner be there for me when I need them.** *

Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

19. **Communicating with my partner using technology when I am having a bad day helps me feel better.** *

Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

20. **Communicating with my partner using technology helps me feel less worried about something.** *
Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

21. **I worry that my partner would feel obligated to contact me using this technology.** *
Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

Affective benefits page 3

For these questions, the word "technology" refers to whichever system you selected in the previous question, one of:

Start of study, communications only
Synchronous TV with communications
Synchronous music with communications

22. **I have to talk to my partner using technology even if I don't want to.** *
Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

23. **I feel guilty if I don't answer a contact my partner makes using technology.** *
Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

24. **I have to answer when my partner tries to contact me using technology even if I don’t want to.** *
Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

25. **I feel sad when my partner isn't around when I try to contact my partner using technology** *
Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

26. **I feel sad when my partner takes too long to respond when I try to contact my partner using technology.** *
Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

27. **I worry that I am not meeting my partner’s expectations for our contact using technology.** *
Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

28. **I feel sad when my partner doesn't pay enough attention to me when we use technology.** *

Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

Affective benefits page 4

For these questions, the word "technology" refers to whichever system you selected in the previous question, one of:

Start of study, communications only
Synchronous TV with communications
Synchronous music with communications

29. **I worry that my partner might learn something using technology that I want to keep secret.** *

Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

30. **I worry about my privacy while my partner and I are using technology together.** *

Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

31. **I worry that others may overhear or see something that my partner and I share using technology.** *

Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

32. **I worry that I am violating my partner's privacy during our contact using technology.** *
Mark only one oval.

- Never
- Rarely
- Sometimes
- Usually
- Always

Social Presence and Connectedness

33. **I often felt as if my remote companion and I were in the same room together** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

34. **My remote companion was often aware of me** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

35. **My remote companion paid close attention to me** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

36. **I was easily distracted from my remote companion when other things were going on** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

37. **I was sometimes influenced by my remote companions moods** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

38. **My remote companion was able to communicate their intentions to me** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Strongly disagree

39. **My thoughts were clear to my remote companion** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Strongly disagree

40. **My actions were often dependent on my remote companions actions** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Strongly disagree

41. **The behaviour of my remote companion was often in direct response to my behaviour** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Strongly disagree

Post-study questionnaire

For these questions, the "system" refers to the CastAway synchronous TV system you have been using, with questions examining your use of this for consuming TV content (e.g. programmes) and music content seperately.

*Required

1. **Name** *

   ....

2. **Group** *

   Mark only one oval.

   - ( ) A
   - ( ) B
   - ( ) C
   - ( ) D
   - ( ) E
   - ( ) F
   - ( ) G
   - ( ) H
   - ( ) I
   - ( ) J

TV content

3. **I think this synchronous TV system is useful to me** *

   Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree	( )	( )	( )	( )	( )	( )	( )	Strongly disagree

4. **It would be convenient for me to have this synchronous TV system** *

   Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree	( )	( )	( )	( )	( )	( )	( )	Strongly disagree

5. **I think this synchronous TV system can help me with many things** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

6. **I would have positive feelings toward using this synchronous TV system** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

7. **I think synchronous TV would make my life more interesting** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

8. **It would be a good idea to use this synchronous TV system** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

9. **I think i will use this synchronous TV system in the future** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

10. **I recommend the use of this synchronous TV system to others** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

11. **Given the oppurtunity, I would intend to continue using this synchronous TV system in the future** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Strongly disagree

12. **How engaging was it when you viewed TV content with your partner?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Much more engaging	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Much less engaging

13. **How enjoyable was it when you viewed TV content with your partner?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Much more enjoyable	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Much less enjoyable

14. **How emotional was it when you viewed TV content with your partner?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Much more emotional	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Much less emotional

15. **Did our system affect the frequency of synchronous TV consumption you performed with your partner?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Much more frequent	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Much less frequent

16. **Did our system affect the duration of synchronous TV consumption you performed with your partner?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Much longer	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Much shorter

17. **How satisfied were you with the choices of TV content you viewed with your partner?** *
Mark only one oval.

	1	2	3	4	5	6	7	
Very satisfied	◯	◯	◯	◯	◯	◯	◯	Very unsatisfied

18. **It felt like our experiences were synchronized** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree	◯	◯	◯	◯	◯	◯	◯	Strongly disagree

Compared to how you have shared media in the past, when viewing TV together...

19. **...it felt more like my partner and I were interacting naturally, as if we were together** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree	◯	◯	◯	◯	◯	◯	◯	Strongly disagree

20. **...it felt more like I was experiencing the activity with my partner** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree	◯	◯	◯	◯	◯	◯	◯	Strongly disagree

21. **...this experience was more engaging** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree	◯	◯	◯	◯	◯	◯	◯	Strongly disagree

Music content

22. **I think this synchronous music system is useful to me** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

23. **It would be convenient for me to have this synchronous music system** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

24. **I think this synchronous music system can help me with many things** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

25. **I would have positive feelings toward using this synchronous music system** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

26. **I think this synchronous music system would make my life more interesting** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

27. **It would be a good idea to use this synchronous music system** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

28. **I think i will use this synchronous music system in the future** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree	◯	◯	◯	◯	◯	◯	◯	Strongly disagree

29. **I recommend the use of this synchronous music system to others** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree	◯	◯	◯	◯	◯	◯	◯	Strongly disagree

30. **Given the oppurtunity, I would intend to continue using this synchronous music system in the future** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree	◯	◯	◯	◯	◯	◯	◯	Strongly disagree

31. **How engaging was it when you listened to music with your partner** *
Mark only one oval.

	1	2	3	4	5	6	7	
Much more engaging	◯	◯	◯	◯	◯	◯	◯	Much less engaging

32. **How enjoyable was it when you listened to music with your partner** *
Mark only one oval.

	1	2	3	4	5	6	7	
Much more enjoyable	◯	◯	◯	◯	◯	◯	◯	Much less enjoyable

33. **How emotional was it when you listened to music with your partner** *
Mark only one oval.

	1	2	3	4	5	6	7	
Much more emotional	◯	◯	◯	◯	◯	◯	◯	Much less emotional

34. **Did our system affect the frequency of synchronous music consumption you performed with your partner?** *

Mark only one oval.

	1	2	3	4	5	6	7	
Much more frequenct								Much less frequent

35. **Did our system affect the duration of synchronous music consumption you performed with your partner?** *

Mark only one oval.

	1	2	3	4	5	6	7	
Much longer								Much shorter

36. **How satisfied were you with the choices of music content you listened to with your partner?** *

Mark only one oval.

	1	2	3	4	5	6	7	
Very satisfied								Very unsatisfied

37. **It felt like our experiences were synchronized** *

Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

Compared to how you have shared media in the past, when listening to music together...

38. **...it felt more like my partner and I were interacting naturally, as if we were together** *

Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree								Strongly disagree

39. **...it felt more like I was experiencing the activity with my partner** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree	◯	◯	◯	◯	◯	◯	◯	Strongly disagree

40. **...this experience was more engaging** *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly agree	◯	◯	◯	◯	◯	◯	◯	Strongly disagree

General questions (consider the system as a whole, both music and TV)

41. **Did our system affect the frequency of your communications with your partner** *
Mark only one oval.

	1	2	3	4	5	6	7	
Much more frequent	◯	◯	◯	◯	◯	◯	◯	Much less frequent

42. **Did our system affect the duration of your communications with your partner** *
Mark only one oval.

	1	2	3	4	5	6	7	
Much longer	◯	◯	◯	◯	◯	◯	◯	Much shorter

43. **Did our system affect the quality of your communications with your partner** *
Mark only one oval.

	1	2	3	4	5	6	7	
Much better	◯	◯	◯	◯	◯	◯	◯	Much worse

44. **To what extent did technical problems stop you from using the system** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely (i.e. there were many technical problems)	◯	◯	◯	◯	◯	◯	◯	Not at all (system worked fine)

45. **What interaction made you feel most connected with your partner** *

Mark only one oval.

- ( ) Text chat
- ( ) Audio chat
- ( ) Video
- ( ) Video + audio chat

University of Glasgow

Plain Language Statement

1. Study title and Researcher Details

Cast Away - TV at-a-distance

Researcher: Mark McGill m.mcgill.1@research.gla.ac.uk (PhD Student 0303456)
Supervisor: Professor Stephen Brewster Stephen.Brewster@glasgow.ac.uk

IMPORTANT

In order to take part in this study, you must be aged 18 or over, have access to a TV with HDMI port, and an unlimited high-speed broadband connection, and suffer no visual or auditory impairments (i.e. you are able to take part in a video call). You will need to provide a partner with which to conduct the study, who will also need to read this document and reply to the associated consent form in order to take part. You must both reside in the UK.

2. Invitation paragraph

You are being invited to take part in a paid study, which should take approximately **1 week** to complete. Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Take time to decide whether or not you wish to take part.

If there is anything that is unclear, or you would like more information, or you have any questions, please feel free to raise these concerns with the researcher present. If you wish to discuss any aspect of this study at a later date, contact us at the email addresses listed above. Alternatively, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at the following email address: Peter.Uhlhaas@glasgow.ac.uk

3. What is the purpose of the study?

The purpose of this study is to investigate at-a-distance shared TV experiences. By "at-a-distance shared TV experiences", we are referring to the capability to have the TVs in multiple places synchronized, such that if a programme plays on one, it also plays on the other. For this study, we will be using smartphone devices that support Google Chromecast, allowing for a selection of applications (BBC iPlayer, Google Play Music) to have their content sent to multiple TVs at once across any distance (within the UK).

In this study, pairs of participants that know each other will be given a complete system for at-a-distance TV usage, allowing them to initiate shared Chromecast sessions, and cast content to both TVs at the same time. Additionally the smartphones provided will be equipped with software to allow participants to communicate with each other, be it textual, speech, or video communications.

4. Why have I been chosen?

Your participation has been solicited through emails or notice board postings to which you replied, and you have indicated you are in a long distance relationship of some form (be it having a partner, friend, or family residing in another household to which you currently reside).

5. Do I have to take part?

Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

6. What will happen to me if I take part?

You will be asked to use the provided system over the course of a week, watching and listening to content with your partner at-a-distance (i.e. when in different households in the UK) and using the communications facilities provided if you wish to communicate with your partner during these sessions.

Your activity on the smartphone will be logged and recorded. Your communications activity will also be logged in a limited form:

- Text chats will be logged in terms of length (number of words, number of characters), when typing started, when messages were sent, but **not** content.
- Voice chats will be logged in terms of when this functionality was turned on/off. They **will additionally be recorded on the device**, for future automated analysis in order to determine how much vocal communication occurred.
    - This data will be listened to by the experimenter in a limited capacity i.e. listening to the first 20 seconds of a recording for calibration purposes, after which the speech will be automatically analysed. **This data will reside on the device until the device is returned to the experimenter, meaning that you can review this recorded speech data, and delete recordings if you so wish.**
- Video data will be logged in terms of when this functionality was turned on/off but **not** content.

Throughout the course of the study you will periodically be interviewed and asked to complete questionnaires regarding your usage of the system, and the effect it is having on your relationship with your partner. At the end of the study you will then be debriefed and asked to answer some questions to help us better understand the experience you have undertaken. For taking part, you will be paid £50.

7. Will my taking part in this study be kept confidential?

Yes, all data collected from you will be treated confidentially, will be seen in its raw form only by the experimenters, and if published will not be identifiable as coming from you. Please do not to log in to any personalized web services on the devices provided whilst taking part in the experiment, as all content entered will be recorded.

8. What will happen to the results of the research study?

The results of the study may appear in a Doctoral thesis, and a number of published studies, again all in a confidential format where anonymity is preserved.

9. Who is organising and funding the research?

This project is part of an industrial studentship PhD part sponsored by Bang & Olufsen, being conducted at the University of Glasgow.

10. Who has reviewed the study?

This study adheres to the BPS ethical guidelines, and has been approved by the College of Science and Engineering ethics committee of The University of Glasgow (ref: D1437554107627).

11. Contact for Further Information

Whilst you are free to discuss your participation in this study with the researcher, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at Peter.Uhlhaas@glasgow.ac.uk

For further information, or if you wish to receive a summary of the findings of this experiment at a later date, please contact the researcher or the supervisor of this project, details listed below.

Researcher - Mark McGill
Email: m.mcgill.1@research.gla.ac.uk
Tel: 07791201325
Address: Room F122
17 Lilybank Gardens
Glasgow, G12 8RZ, UK

Supervisor - Professor Stephen Brewster
Email: Stephen.Brewster@glasgow.ac.uk
Tel: +44 (0)141 330 4966

CastAway Study – User Guide

Contents

1 Introduction

The system you're going to be trialling allows you and your partner to communicate with each other whilst watching programmes together on BBC iPlayer, and listening to music together on Google Play Music, with playback loosely synchronized.

You should have received the following equipment:

- **Chromecast TV dongle** (+HDMI extension cable, +usb power plug with cable)
- **Nexus 5 Android smartphone** (+usb power plug with cable)
- **Label and postage for returning equipment** (optional, if you received equipment via the post)

You will find instructions on how to set the equipment up over the coming pages, and there's a schedule on the next page that outlines your participation in this study over the course of the week.

2 Pre-requisites

- Fast unlimited internet connection (no torrenting while using the app please ☺)
- TV with HDMI port

3 Schedule

- Received equipment (Now ☺)
  - If you could please read this document, and complete the setup of the system (see **Section 4**)
  - After this, please complete the **pre-study questionnaire**. You may have received a printed copy of this (labelled pre-study questionnaire), but if possible can you fill the electronic version out instead, at: https://goo.gl/W6qglB (all URLs were in your welcome email too)
- Both you and partner have received equipment and setup system
  - **Let each other know when you are ready**, then **follow the instructions in section 5** and verify the system and communications capabilities are working correctly, and that you understand how to use the apps.
  - Once you understand how everything works, we'd like you to **test the communications out** thoroughly. Start a sync session as described, but don't start any synchronous Chromecast activities. Instead, please use the communications functionality to chat to your partner however you see fit, **for 10 minutes**. After this, please fill out **the connectedness questionnaire** https://goo.gl/GVxyHz on the basis of how you feel communicating with your partner via phones/devices
- At this point, **the study has started**
  - We'd like you to **keep the equipment for approximately 1 week** (6 days is fine, provided you have the system over a weekend). Use the system for synchronous TV and music consumption however much you want. We only ask that you use the system at **least once for TV viewing with your partner, and at least once for music listening with your partner.**
  - Furthermore, once you are familiar with and have used the TV and music functions with your partner, then we'd ask that immediately after viewing TV or music content on one of these occasions, if you could fill out the **connectedness questionnaire** https://goo.gl/GVxyHz, once each for TV and music respectively
- **Once your week is over** and you are at the end of the study
  - Please fill out one final questionnaire, the **post-study questionnaire** https://goo.gl/sK2J5d
  - After this, **if you are participating at a distance**, and won't be meeting the experimenter, if you could take the Nexus 5, and open up the "Easy Voice Recorder" app, select record, then speak answers to the following questions regarding your experience:
    - Did this technology help or hinder your relationship?
    - Did the system make you feel closer or more connected to your partner? Why do you think it had this effect?
    - What were your thoughts on synchronous music? Did you like or dislike it?
    - What were your thoughts on synchronous TV? Did you like or dislike it?
    - Were you happy with the media choices and level of control you had over the experiences?
    - Did you ever find using the system a burden, or intrusive?

        - Any overall thoughts or opinions, likes and dislikes, on the system you tried out, or synchronous TV experiences in general?
    - Finally, return the devices to the experimenter. Package them in the box you received them, and attach the return label and postage provided (stick all the stamps on the box). This should be enough to pay for next day delivery, you just need to take the parcel to the post office. Please do this as soon as you are able, so I can pass the devices off to the next participants ☺
- Payment after completion
    - Once the devices are returned, if you are returning them in person you'll be paid in cash. If you are returning them at a distance, I'll contact you and arrange payment via Paypal, or BACS, whichever you prefer.

If there are any problems, see the troubleshooting section in this document, or contact me. You can email me at m.mcgill.1@research.gla.ac.uk or hangouts me at mmcgill@gmail.com or text me at 07791201325. If there are any problems using the system please let me know, and I'll try to get back to you ASAP.

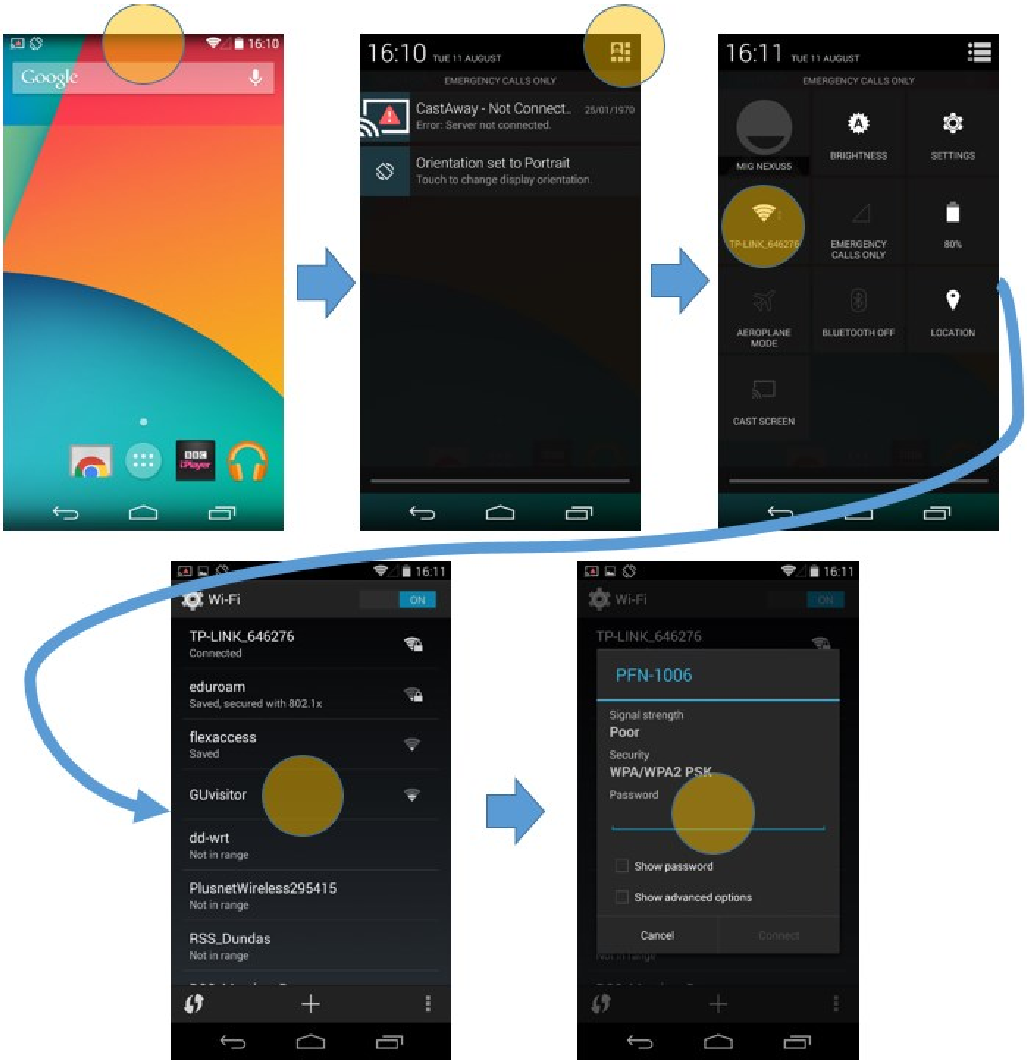
Thanks for taking part in this study, it's greatly appreciated!

4 Setup

To complete the setup, you'll need to know the name of your WiFi point, and the password to connect to it.

Nexus 5 (phone)

Firstly, turn the Nexus 5 on, by pressing the power button, on the top-right side of the device. Once the device has started up, click the "Settings" icon, select "Wi-Fi", then select your Wi-Fi point name and enter your password. At this point the phone should be connected to the internet.



Chromecast (hdmi dongle)

(N.B. A pictorial guide for this step can be found in the inside of the Chromecast box)

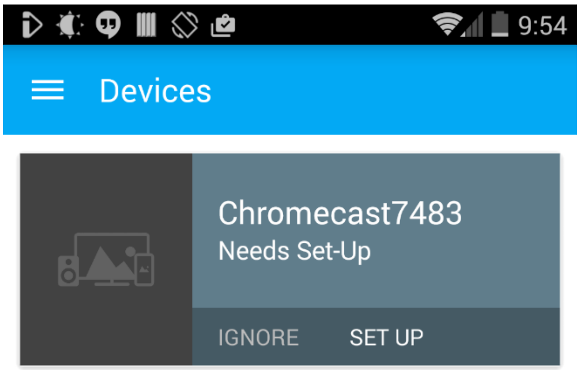
Plug the Chromecast dongle into your TV. The metallic end of the Chromecast is the HDMI connector, which goes into the HDMI port of your TV. Once it is attached to the TV, plug the power adaptor in nearby, and connect the cable from the power adaptor to the other end of the Chromecast dongle. At this point the dongle should light up to indicate it is receiving power.

Turn your TV on, and change the source/input to your HDMI port (usually involves pressing a “source” button on your TV remote control). You should see the Chromecast screen appear on your TV, stating it is unable to connect to the internet.

Now return to the Nexus 5 device, and select the Chromecast app icon.

The Chromecast app should find your Chromecast, at which point you will be given the option to setup the device, entering your Wi-Fi details once more. Please make sure the Chromecast is connected to the same Wi-Fi point as the Nexus 5. Also when setting the Chromecast up, please make sure that it is named whichever of the following names is highlighted:

Experiment CC1 *or* Experiment CC2 *or* Experiment CC3 *or* Experiment CC4

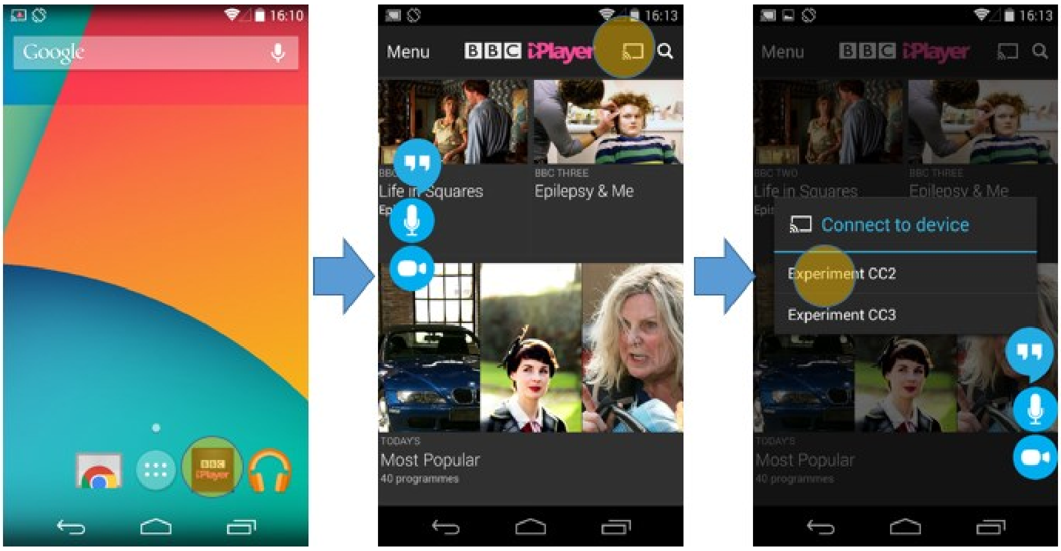


Once this is all done, your TV should display the Chromecast home screen (usually some nature picture).

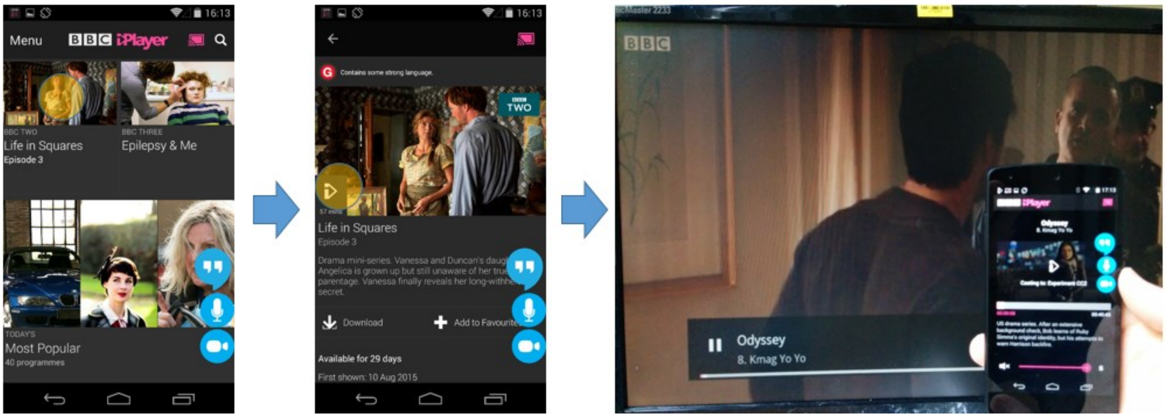
.

Testing that Chromecast is working

To check the Chromecast is working, select the iPlayer icon on the Nexus 5, then select the Chromecast icon (pictured below). Then select your Chromecast (labelled “Experiment CCX”) and the application should connect.



Once it has connected (the Chromecast icon will turn pink), select any programme, and hit play, and the programme should play on the TV.



If this happens, you have successfully setup the Chromecast. If not, please check your internet connection is functional, and both the Nexus 5 and Chromecast are connected to your Wi-Fi point, and that the Chromecast is both plugged into the TV, and to the power cable provided. Hit the icon in the iPlayer app and select disconnect to stop playback.

5 Using CastAway app

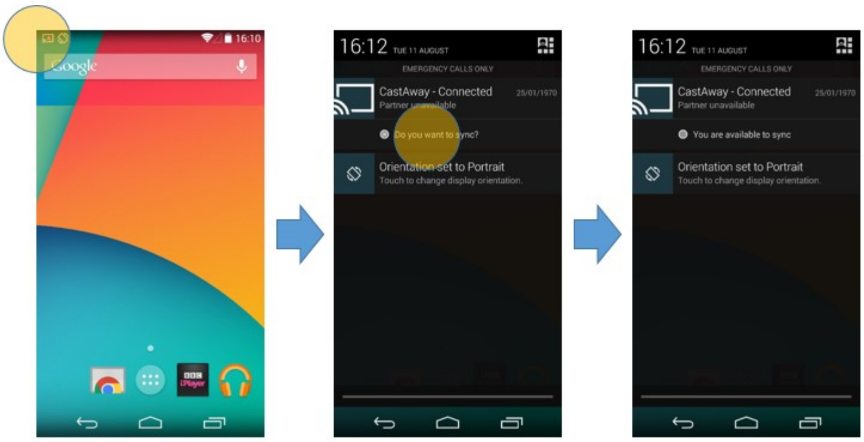
First, make sure the app is connected to both the Chromecast and the server. Pull down the notification tray, and the apps notification will tell you if it isn't connected to either.

If it states "**Chromecast not connected**", press the button in the top right corner (see troubleshooting section for a picture), and wait until the Chromecast icon appears on this screen in a few seconds, then press this button once more to confirm the notification has changed. If it still says the Chromecast isn't connected, you may need to restart this device, and the Chromecast, and check both are connected to your wifi network and that the Chromecast has the correct name.

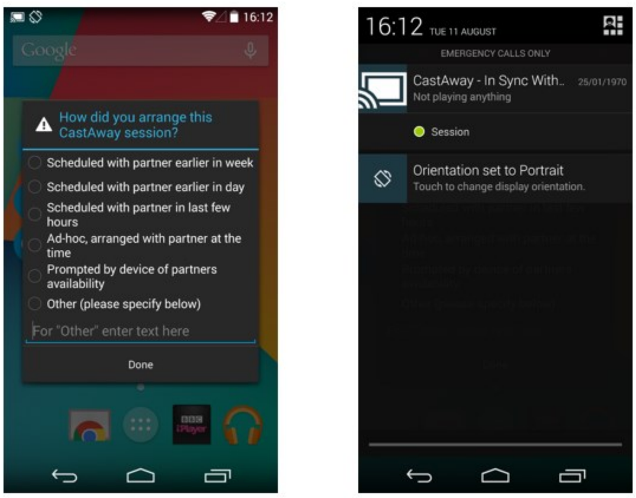
If this notification states "**Server not connected**", this means the device cannot connect to our communications server. Check the device is connected to the wifi, and that your internet connection is functioning correctly.

Connecting to partner

If you wish to make yourself available for a synchronous casting session, press the "Available" button on the notification. If your partner's device is on, they will receive a notification that you are available.



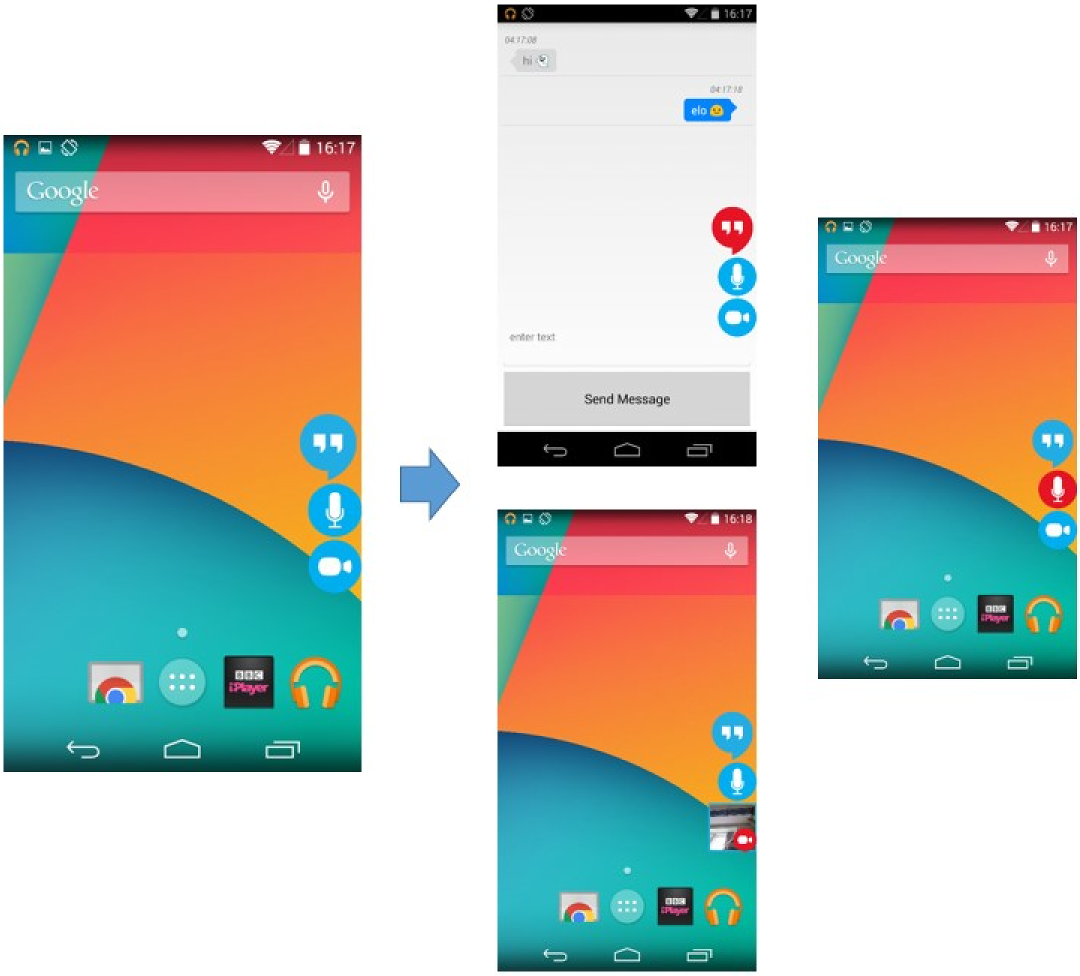
When you are both available, the notification will change to look like this:



This means that you are now connected and in sync with your partner. Any Chromecast activity you perform on the Nexus 5 in either the BBC iPlayer or Google Play Music apps will occur on both your TV and your partners TV. If the status of the session changes at all, you will receive a notification and the text in the notification will change to tell you what has happened.

Communicating with partner

Additionally, when you close the notification drawer, you will see the following has appeared on the screen:

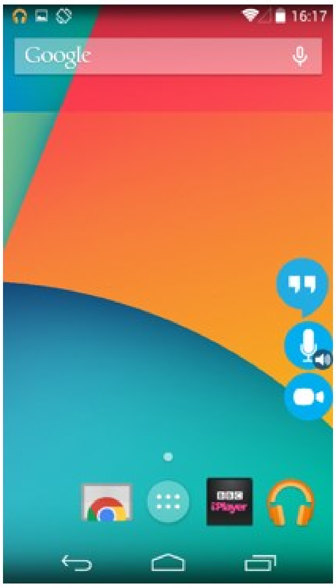


These on-screen icons are how you can communicate with your partner when using the system. By placing your finger on the quotation mark, you can move the position of the icons.

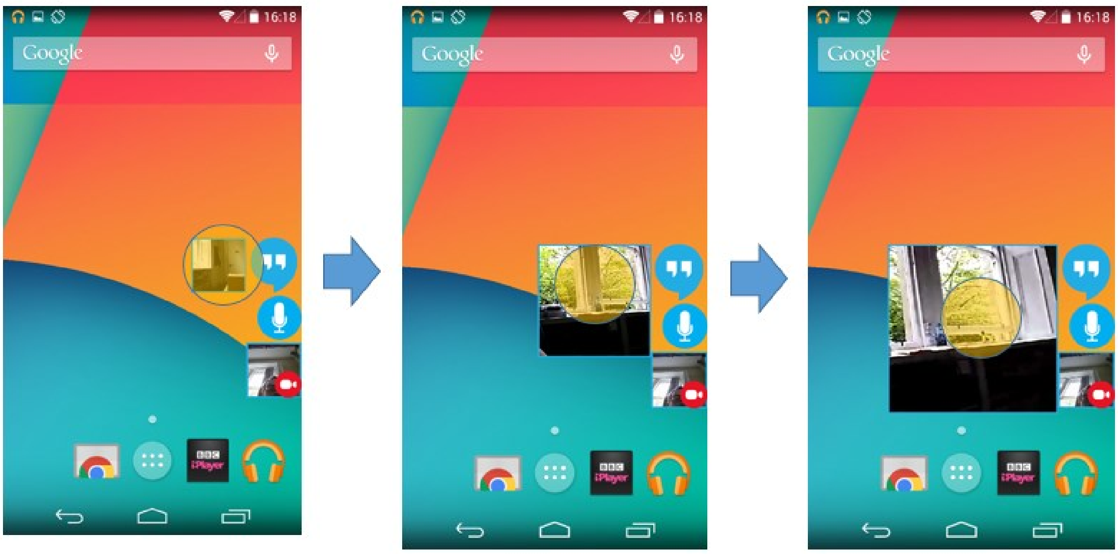
- Tapping the quotation mark opens the text chat dialog.
- Tapping the Speaker icon turns on your microphone, sending your captured voice to your partner.
- Tapping the video icon turns on your front-facing webcam, sending said video to your partner.

In this way, you can choose what mediums you wish to communicate with your partner with, and when. Note that this is one-way: what you do doesn't affect what your partner chooses to do, so if you select audio but your partner does not, that means your partner can hear you, but you cannot hear your partner.

When you are receiving audio from your partner, the audio icon will change, with a small speaker icon appearing inset as below:



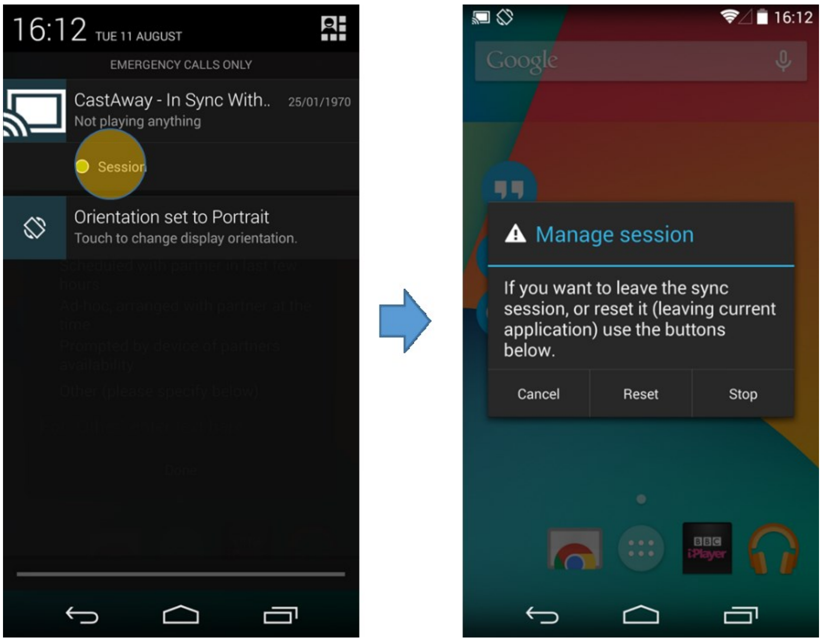
When receiving video from your partner, a box will appear with their view as seen below. Tapping on this box will cycle between 3 sizes of view: small, medium, or large.



The microphone on the device is located near the top. If you want to delete any recordings of your audio, open the Music app up, select "Downloaded only" in the left menu, then browse to participant-audio-logs – the files are listed by date and time.

Managing your session

If you want to stop being in sync with your partner, or if you encounter a problem and wish to reset the session and leave the current application, drag down the menu bar and select the Session button on the notification, as below:



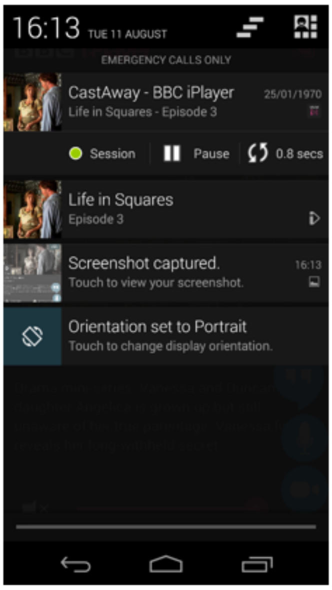
Chromecast Applications

CastAway supports two Chromecast applications, **BBC iPlayer** and **Google Play Music**. If you encounter a problem with either application and wish to reset the session

BBC iPlayer

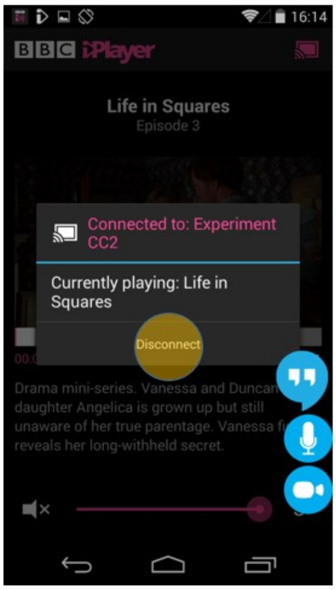
This application works largely as you have experienced before in the setup section of your guide. When you connect to your Chromecast during a synchronous session, the majority of your actions occur both on your TV and your partners TV e.g. playing a TV programme, pausing the programme, seeking to a particular time in that programme, disconnecting from the Chromecast and stopping the programme. You can connect to iPlayer when your partner is already playing a program, and the program will still continue playing, whilst the iPlayer app will give you more control over your experience (e.g. volume, subtitling).

When either of you plays a program on iPlayer, your CastAway notification will change to tell you what is playing, and give you control over pausing playback, as well as providing information as to how "in-sync" you are with your partner, meaning how many seconds your positions in the program differ.



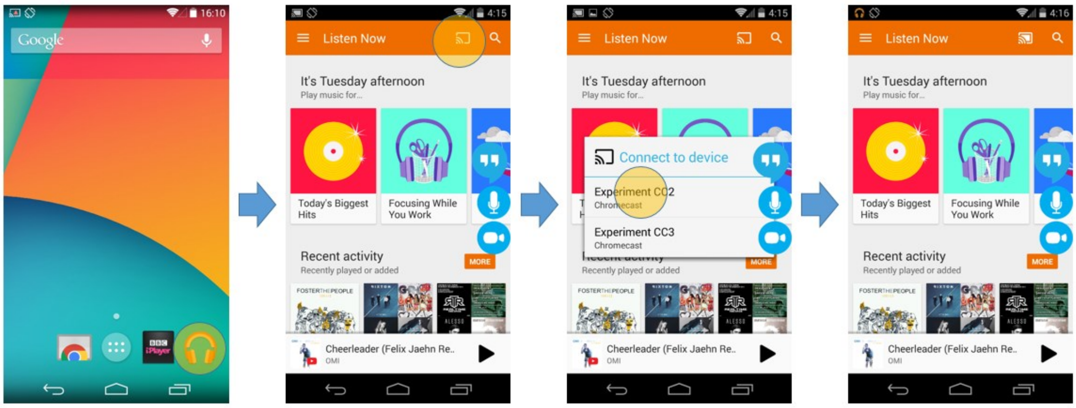
Hitting the Sync button on the right will attempt to re-synchronize playback; if you find the program is too out-of-sync for you both (perhaps due to a slower broadband connection causing a partner to lag behind), press this button and wait 5-10 seconds to see if it resolves your problem. If after 20 seconds it hasn't resolved your problem, try again. If it still has not resolved your problem, one of your internet connections may be slower than usual.

To stop the iPlayer app, select the Chromecast icon and hit disconnect.



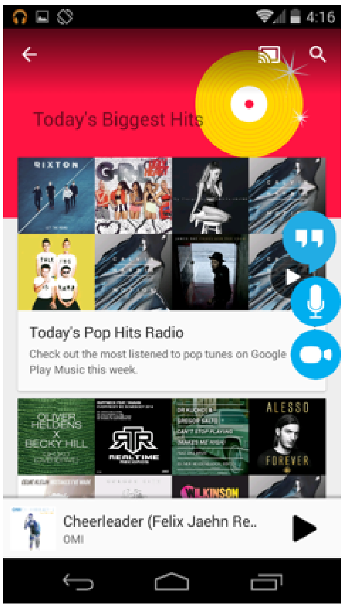
Google Play Music

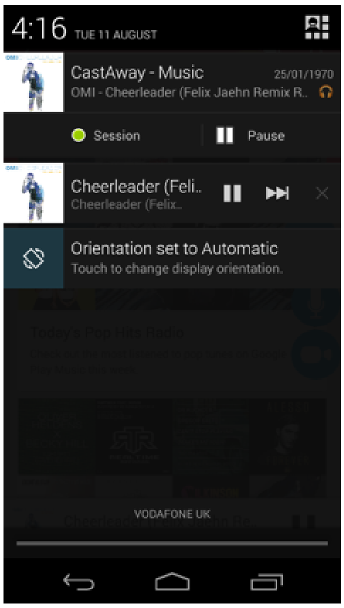
Connecting to this application is very similar to iPlayer, as can be seen below. When connected, you can playback any "cloud" media on both devices, e.g. playlists, albums, and tracks.



However**, there are two noticeable differences / bugs compared to iplayer**:

- Only one person can control the music session at any one time. If your partner is playing music using this application and you connect to the application, playback will cease as the application restarts. Also you will have **to follow the connection sequence twice** at this point for the app to connect successfully (i.e. hit the Chromecast button, wait a few seconds, then try again – you can see it hasn't connected on the first time as the Chromecast icon remains in the disconnected state). When a track or playlist is being played, the CastAway notification will change, giving you the option to pause the track if you so wish.

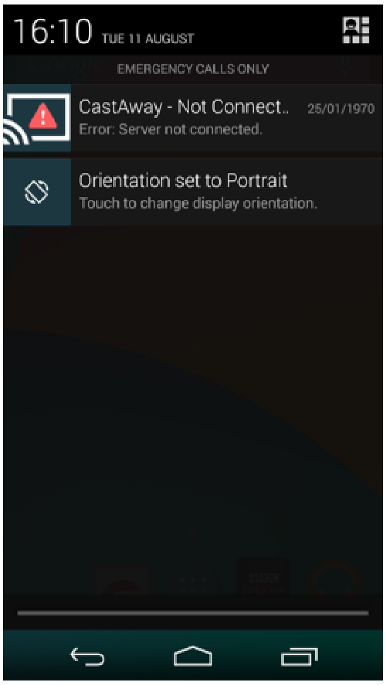




- Seeking in a track (e.g. trying to move to 3 mins in a track) doesn't work, so you can't skip to half-way through a track, as your partners playback will remain at the same time.

6 Troubleshooting

If this notification has a red warning in the icon, this means there has been a problem.



If it states “**Chromecast not connected**”, press the button in the top right corner of the picture above, and wait until the Chromecast icon appears on this screen in a few seconds, then press this button once more to confirm the notification has changed. If it still says the Chromecast isn’t connected, you may need to restart this device, and the Chromecast, and check both are connected to your wifi network. Also check the Chromecast is named correctly, the app is expecting to connect to a Chromecast with a given name, Experiment CCX where X changes depending on participant. You can find your name in the setup section of this document.

If this notification states “**Server not connected**”, this means the device cannot connect to our communications server. Please check your internet connection is working. If it is, please contact me.

The system is heavily reliant on you having a good internet connection, things like video breaking up, audio breaking up, or significant latency might indicate problems with you or your partner’s connections. If this occurs, try to stop any devices that might be downloading content, and perhaps try using the system at later hours when there is less contention from neighbours.

If anything breaks or goes weird (e.g. partner is sending video and you can’t see it), end the session and try again – if that doesn’t work, restart the phones. But that shouldn’t happen hopefully ☺

J. VR Usability Questionnaire

The following questions constituted the questionnaire from Chapter 7 regarding VR usability, as well as an overview of the results.

Overview

You are being invited to take part in a questionnaire regarding the usability of Virtual Reality Head-Mounted DIsplays (VR HMDs), which should take approximately 10 minutes to complete. **You don't have to be a user of VR HMDs to participate!** Before you continue, please take time to read the following information carefully. If there is anything that is unclear, or you would like more information, please feel free to contact us, at the email addresses listed below. Participation is optional, and the questionnaire can be exited at any time. You must be aged 18 or over to take part.
Researcher (PhD Student): Mark McGill Supervisor: Professor Stephen Brewster

What is the purpose of this study?

The purpose of this study is to gain an insight into current VR HMD usage habits (e.g. where are they used, what for, who is present etc.), as well as investigating potential day-to-day issues with their usage.

What will happen if i take part?

You will be asked to answer a series of optional questions, predominantly multiple choice, with some optional written statements, lasting approximately 10-12 minutes in total. All information will be stored securely and kept anonymous. There is a completely optional question asking for your name and email address, if you wish to be notified of further studies in this area, but this information will be kept confidential and will be used only for contact purposes in the event of future research. For taking part in the survey, you will be entered into a draw for a £10 Amazon gift voucher (contact email required).

Similarly, there is an optional question asking respondents to email us a picture of their typical VR HMD usage environment; these pictures may potentially be used in a publication, however with any obviously personally identifiable details censored/blurred. If you wish to take part in this aspect of the survey, please read the requisite question thoroughly and tick the checkbox in the form then email us your picture (n.b. if you do not tick the box, we cannot use your picture).

The results of this study may end up being used in research publications, and possibly a doctoral thesis, but again with emphasis that all results will be anonymized. By hitting the "next" button you give your consent for the data you provide to be used, as described above.

This project is part of an industrial studentship PhD being conducted at the University of Glasgow.

* 1. How often do you use virtual reality headsets?

- Daily
- Weekly
- Monthly
- Yearly or less often
- Never

2. What VR HMD have you used?

- [ ] Oculus Rift DK1
- [ ] Oculus Rift DK2
- [ ] Carl Zeiss Cinemizer
- [ ] Silicon Micro Display ST1080
- [ ] Sony HMZ-T1
- [ ] Sony HMZ-T2

Other (please specify)

3. What applications do you use VR HMDs for?

- [ ] Gaming / Interactive experiences
- [ ] Media (e.g. films, TV)
- [ ] Productivity
- [ ] Therapeutic
- [ ] Simulation
- [ ] Modelling

Other (please specify)

4. How do you typically experience audio feedback (e.g. game audio) when using a VR HMD?

- ◯ In-Ear headphones
- ◯ Enclosed headphones
- ◯ Noise cancelling headphones
- ◯ Bone-conduction headphones (or other equivalent where you can hear the real world)
- ◯ Speakers
- ◯ No audio

Other (please specify)

5. When using VR HMDs, are there any aspects of their usage or usability that annoy or frustrate you?

6. To what extent do you agree that the following IMPEDE your ability to use and enjoy VR HMDs?

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Technical capabilities of headset (e.g. head tracking, resolution, latency)	◯	◯	◯	◯	◯
Nausea when using headset	◯	◯	◯	◯	◯
Fidelity of virtual world (e.g. how real does it look)	◯	◯	◯	◯	◯
Awareness of real world (e.g. who is there)	◯	◯	◯	◯	◯
Interacting with real world objects (e.g. picking up a cup)	◯	◯	◯	◯	◯
Interacting with real world peripherals (e.g. via keyboard, mouse, motion controllers..)	◯	◯	◯	◯	◯
Providing input to the virtual world (e.g. via peripherals, gesture, voice etc.)	◯	◯	◯	◯	◯

7. When using the VR HMD, how often do you take the headset off (e.g. lifting it off your eyes temporarily, removing it etc.) in order to interact with, or gain awareness of, the real world?

- Never
- Infrequently
- Sometimes
- Often
- All the time

8. Having to remove the VR HMD in order to interact with reality frustrates me

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

9. When using a VR HMD, I experience anxiety regarding my inability to tell what is happening around me (e.g. someone has entered the room, what they are doing, whether they are watching me)?

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

10. My level of awareness of reality when using a VR HMD is enough that i feel comfortable and secure in my personal surroundings

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

11. In what settings do you use a VR HMD, and how frequently?

	Never	Yearly or more infrequently	Monthly	Weekly	Daily
Someone else's home (shared space)	◯	◯	◯	◯	◯
Someone else's home (private space / predominantly alone)	◯	◯	◯	◯	◯
Your home (shared space)	◯	◯	◯	◯	◯
Your home (private space / predominantly alone)	◯	◯	◯	◯	◯
Work (shared space)	◯	◯	◯	◯	◯
Work (private space / predominantly alone)	◯	◯	◯	◯	◯
In public	◯	◯	◯	◯	◯

Other (please specify)

12. How often do you use VR HMD in the following contexts?

	Never	Infrequently	Sometimes	Often	Always
Alone	○	○	○	○	○
With others present but not observing your actions	○	○	○	○	○
With others present and observing your actions	○	○	○	○	○

Other (please specify)

13. How effectively do you interact with the real world when wearing a VR HMD in the following contexts:

	Extremely Ineffectively	Ineffectively	Neutral	Effectively	Extremely Effectively
Interacting with objects (e.g. a cup)	○	○	○	○	○
Interacting with peripherals (e.g. keyboard, pen input, flight controls etc.)	○	○	○	○	○
Interacting with others (e.g. talking to friends)	○	○	○	○	○

Are there other aspects of interacting with the real world that concern you?

14. Do you agree that VR HMDs should provide ways of enabling easier interaction (e.g. seeing / hearing) with the following:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Interacting with objects (e.g. a cup)	○	○	○	○	○
Interacting with peripherals (e.g. keyboard, pen input, flight controls etc.)	○	○	○	○	○
Interacting with others (e.g. talking to friends)	○	○	○	○	○

15. To what extent are you aware of the following aspects of the real world when wearing a VR HMD?

	Very Unaware	Unaware	Neutral	Aware	Very Aware
Hearing what is happening in the room (e.g. movement, talking)	◌	◌	◌	◌	◌
Surroundings (e.g. knowing you are close to a wall)	◌	◌	◌	◌	◌
Orientation (e.g. knowing spatially where you are in the room and where you are facing)	◌	◌	◌	◌	◌
Presence (e.g. knowing others have entered the room)	◌	◌	◌	◌	◌
Proximity (e.g. knowing how close others are to you)	◌	◌	◌	◌	◌
Attention (e.g. knowing if you are being observed)	◌	◌	◌	◌	◌
Interaction (e.g. knowing someone is trying to talk to you)	◌	◌	◌	◌	◌
Context (e.g. knowing what is happening around you)	◌	◌	◌	◌	◌

Are there other aspects of being aware of the real world that concern you?

16. Do you agree that VR HMDs should provide ways of enabling the following types of awareness:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Hearing what is happening in the room (e.g. movement, talking)	○	○	○	○	○
Surroundings (e.g. knowing you are close to a wall)	○	○	○	○	○
Orientation (e.g. knowing spatially where you are in the room and where you are facing)	○	○	○	○	○
Presence (e.g. knowing others have entered the room)	○	○	○	○	○
Proximity (e.g. knowing how close others are to you)	○	○	○	○	○
Attention (e.g. knowing if you are being observed)	○	○	○	○	○
Interaction (e.g. knowing someone is trying to talk to you)	○	○	○	○	○
Context (e.g. knowing what is happening around you)	○	○	○	○	○

17. How often do you feel symptoms of sickness or nausea from using the VR HMD?

- Never
- Infrequently
- Sometimes
- Often
- Every time

18. Optional. If you use VR HMD, if possible **can you please email a picture of the setting you typically use your VR HMD in** (e.g. desk, living room on couch etc.) to m.mcgill.1@research.gla.ac.uk **. Please check the following box if you are willing to allow us to use this picture in a publication (with any identifiable personal details blurred), illustrating the breadth of contexts in which VR HMD are used.**

Please note that only you may be present in the photo, as we are unable to acquire consent for others outside this survey, however it is not necessary for you to be in the photo.

- Agree

19. Wearing a VR HMD with headphones removes your ability to perceive the real world, impacting your ability to interact with your surroundings or others present. Do you consider this to be a barrier toward your adoption and usage of VR HMDs?

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

20. The lack of awareness regarding who is nearby or what is happening around me would be concerning.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

21. Demographics (email address required to enter draw)

Country:

Email Address:

The survey is now complete. Thanks for taking part!

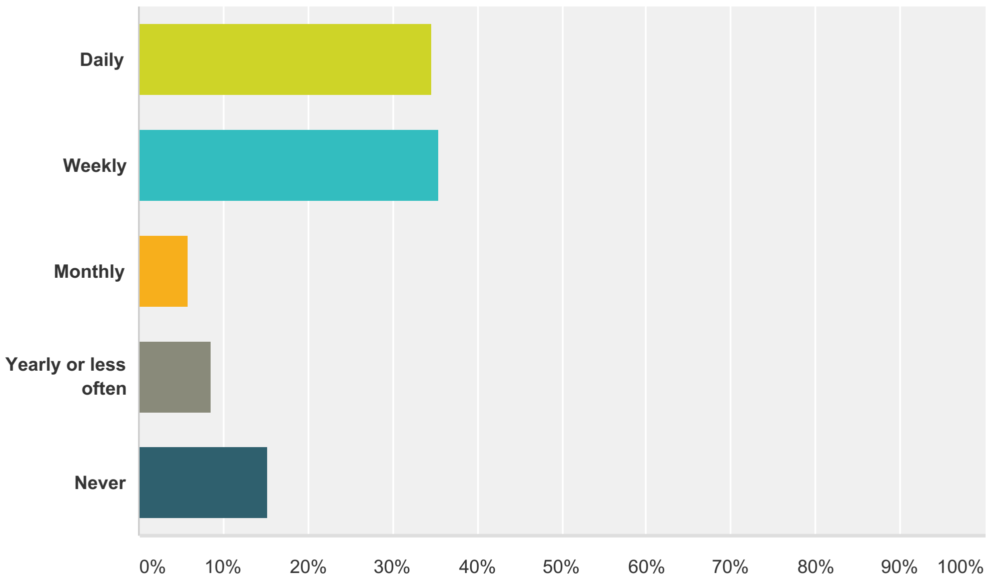
If you have any questions or concerns about the survey, or you wish to receive a summary of the findings of this survey at a later date, please contact us at the email addresses below. Thanks! Your completion of this survey is much appreciated!

Researcher (PhD Student): Mark McGill
Supervisor: Professor Stephen Brewster

This study adheres to the BPS ethical guidelines, and has been approved by the College of Science and Engineering ethics committee of The University of Glasgow (ref: 300130018). Whilst you are free to discuss your participation in this study with the researcher, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at Christoph.Scheepers@glasgow.ac.uk.

Q1 How often do you use virtual reality headsets?

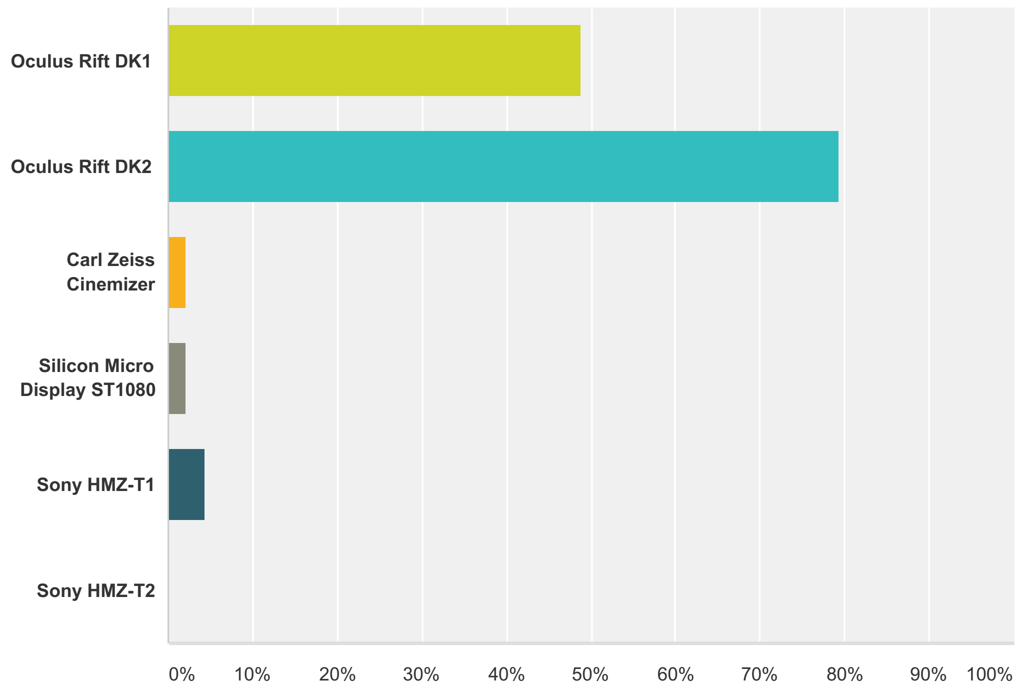
Answered: 118 Skipped: 0



Answer Choices	Responses	
Daily	34.75%	41
Weekly	35.59%	42
Monthly	5.93%	7
Yearly or less often	8.47%	10
Never	15.25%	18
Total		**118**

Q2 What VR HMD have you used?

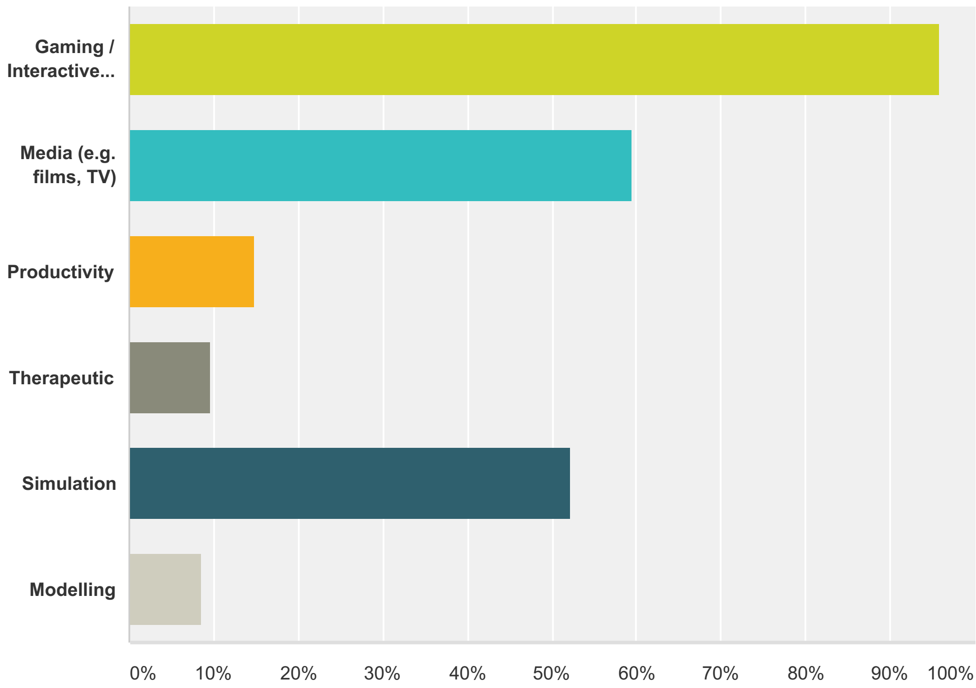
Answered: 92 Skipped: 26



Answer Choices	Responses	
Oculus Rift DK1	**48.91%**	45
Oculus Rift DK2	**79.35%**	73
Carl Zeiss Cinemizer	**2.17%**	2
Silicon Micro Display ST1080	**2.17%**	2
Sony HMZ-T1	**4.35%**	4
Sony HMZ-T2	**0.00%**	0
Total Respondents: 92		

Q3 What applications do you use VR HMDs for?

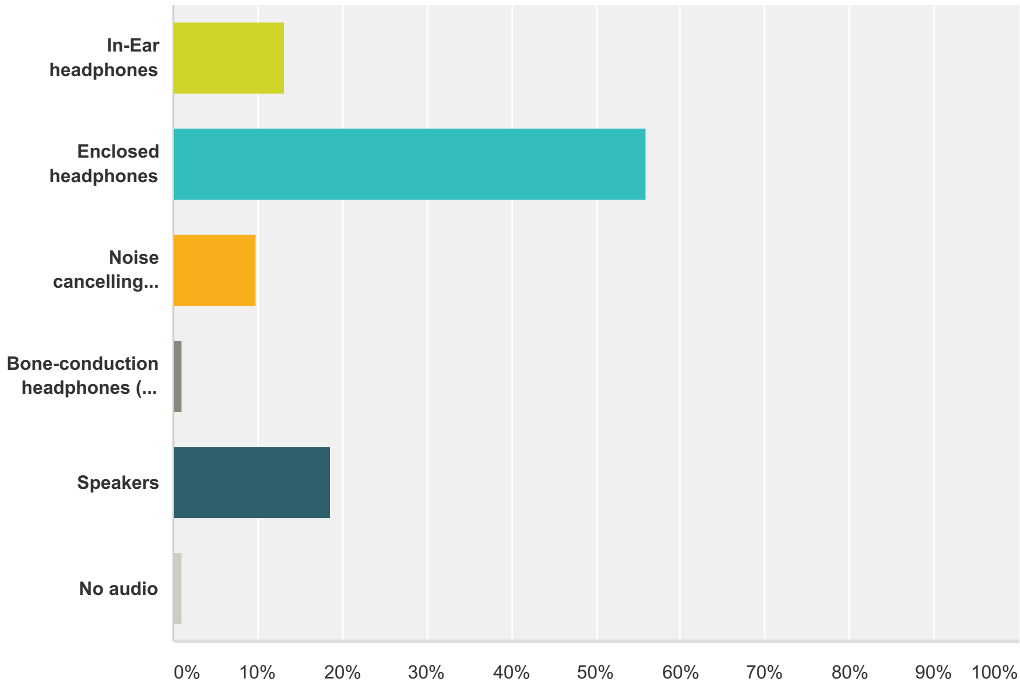
Answered: 94 Skipped: 24



Answer Choices	Responses	
Gaming / Interactive experiences	**95.74%**	90
Media (e.g. films, TV)	**59.57%**	56
Productivity	**14.89%**	14
Therapeutic	**9.57%**	9
Simulation	**52.13%**	49
Modelling	**8.51%**	8
Total Respondents: 94		

Q4 How do you typically experience audio feedback (e.g. game audio) when using a VR HMD?

Answered: 91 Skipped: 27



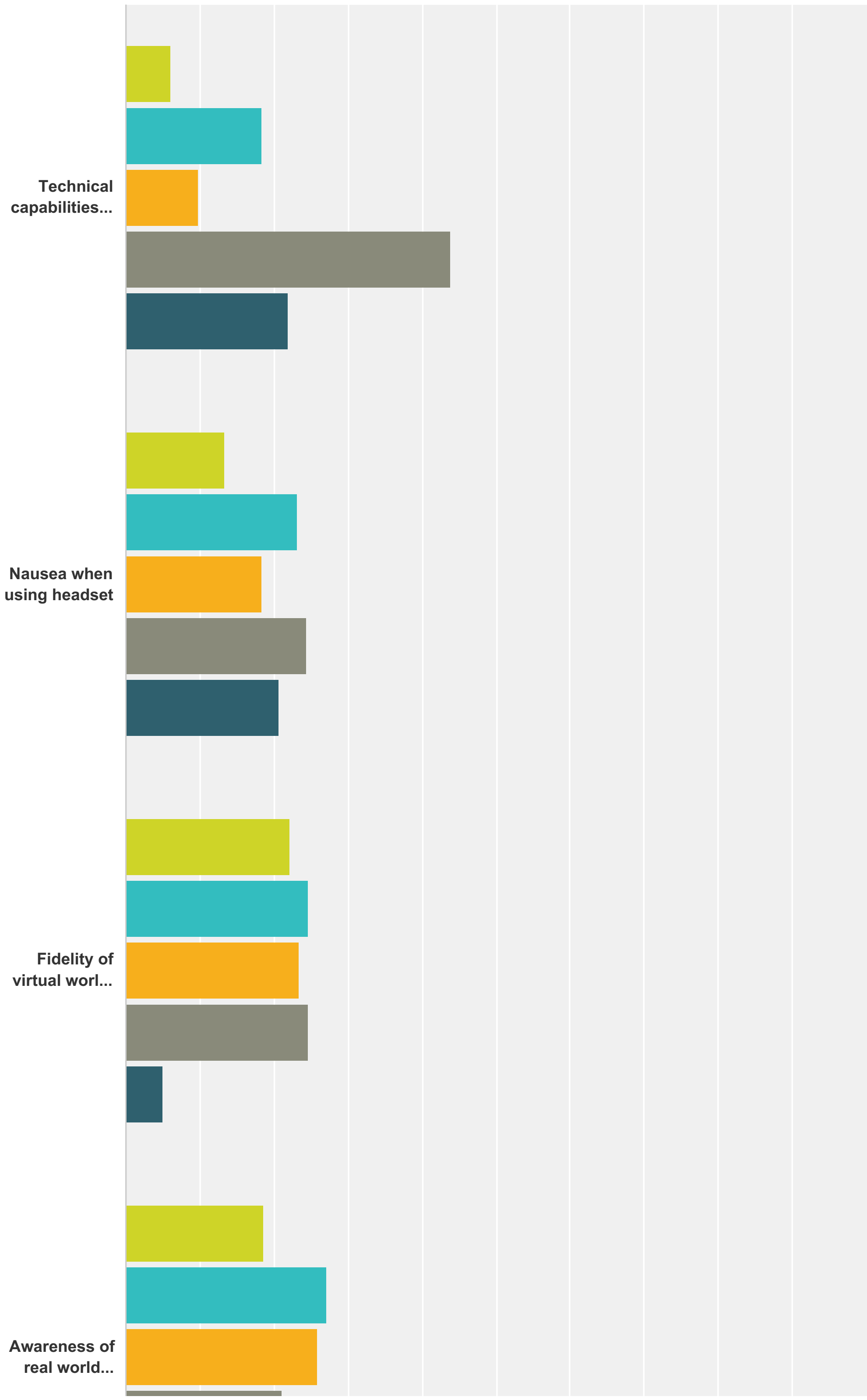
Answer Choices	Responses	
In-Ear headphones	13.19%	12
Enclosed headphones	56.04%	51
Noise cancelling headphones	9.89%	9
Bone-conduction headphones (or other equivalent where you can hear the real world)	1.10%	1
Speakers	18.68%	17
No audio	1.10%	1
Total		**91**

Q5 When using VR HMDs, are there any aspects of their usage or usability that annoy or frustrate you?

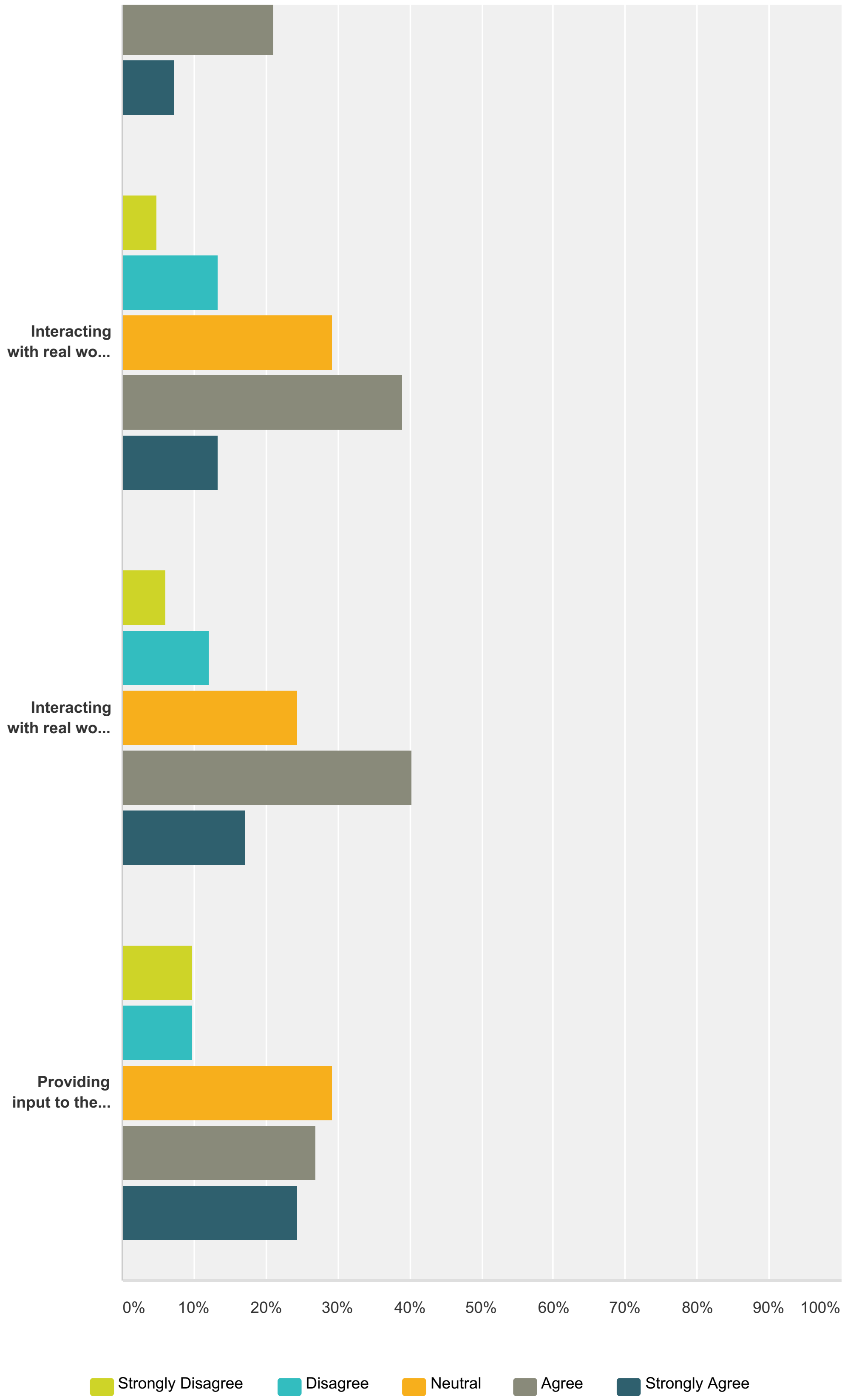
Answered: 62 Skipped: 56

Q6 To what extent do you agree that the following IMPEDE your ability to use and enjoy VR HMDs?

Answered: 82   Skipped: 36



VR Head Mounted Display Usability Survey

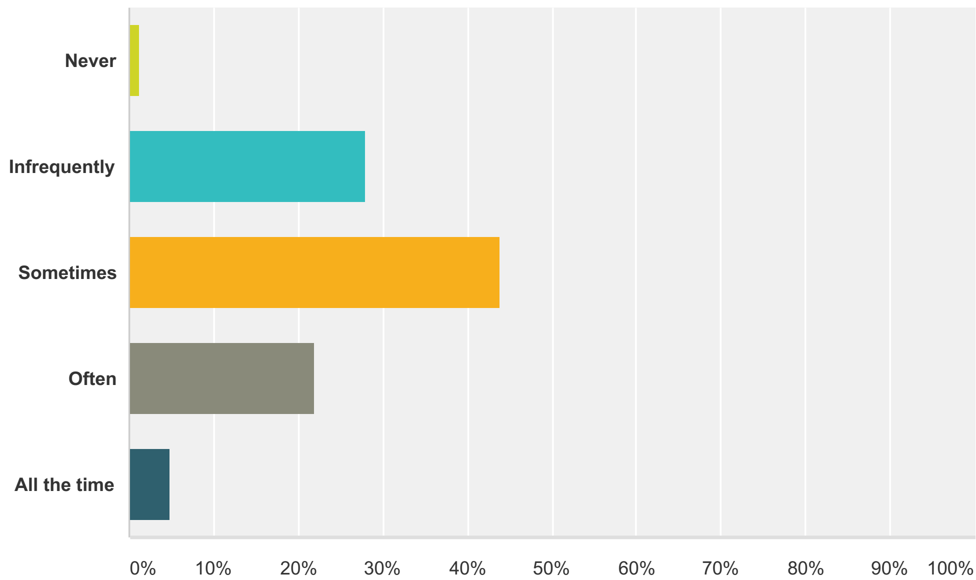


	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Total

Technical capabilities of headset (e.g. head tracking, resolution, latency)	**6.10%** 5	**18.29%** 15	**9.76%** 8	**43.90%** 36	**21.95%** 18	82
Nausea when using headset	**13.41%** 11	**23.17%** 19	**18.29%** 15	**24.39%** 20	**20.73%** 17	82
Fidelity of virtual world (e.g. how real does it look)	**22.22%** 18	**24.69%** 20	**23.46%** 19	**24.69%** 20	**4.94%** 4	81
Awareness of real world (e.g. who is there)	**18.52%** 15	**27.16%** 22	**25.93%** 21	**20.99%** 17	**7.41%** 6	81
Interacting with real world objects (e.g. picking up a cup)	**4.88%** 4	**13.41%** 11	**29.27%** 24	**39.02%** 32	**13.41%** 11	82
Interacting with real world peripherals (e.g. via keyboard, mouse, motion controllers..)	**6.10%** 5	**12.20%** 10	**24.39%** 20	**40.24%** 33	**17.07%** 14	82
Providing input to the virtual world (e.g. via peripherals, gesture, voice etc.)	**9.76%** 8	**9.76%** 8	**29.27%** 24	**26.83%** 22	**24.39%** 20	82

Q7 When using the VR HMD, how often do you take the headset off (e.g. lifting it off your eyes temporarily, removing it etc.) in order to interact with, or gain awareness of, the real world?

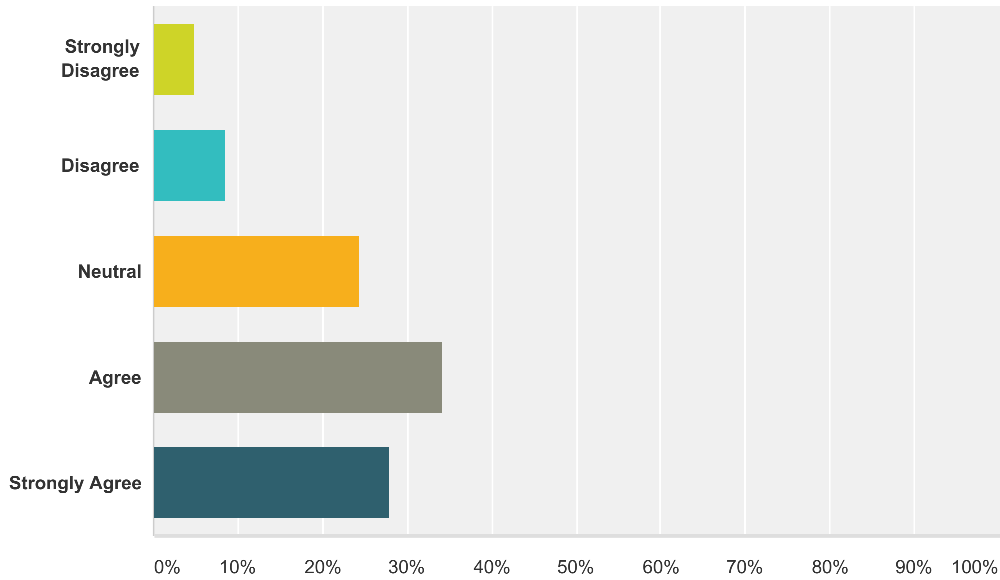
Answered: 82 Skipped: 36



Answer Choices	Responses	
Never	**1.22%**	1
Infrequently	**28.05%**	23
Sometimes	**43.90%**	36
Often	**21.95%**	18
All the time	**4.88%**	4
Total		**82**

Q8 Having to remove the VR HMD in order to interact with reality frustrates me

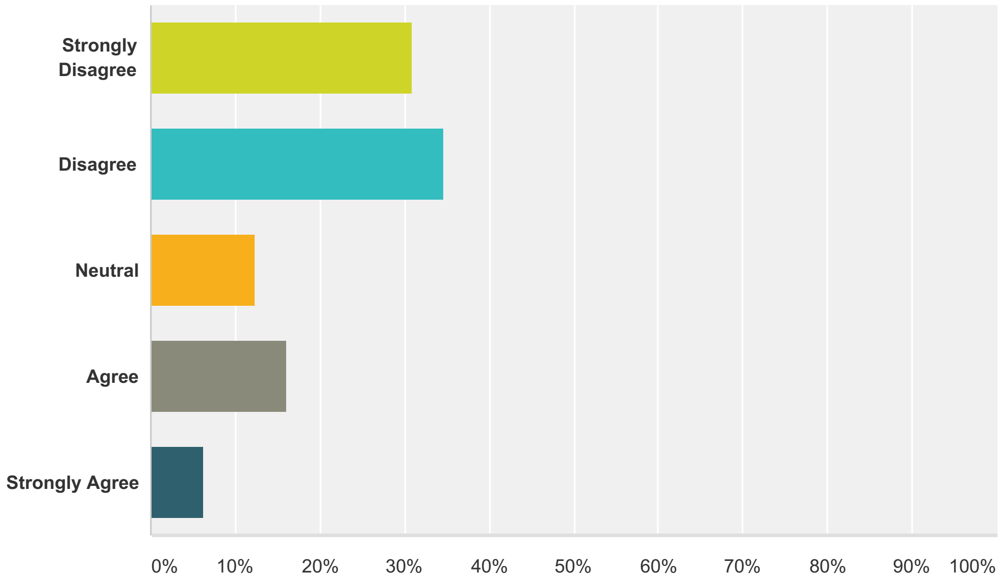
Answered: 82   Skipped: 36



Answer Choices	Responses	
Strongly Disagree	**4.88%**	4
Disagree	**8.54%**	7
Neutral	**24.39%**	20
Agree	**34.15%**	28
Strongly Agree	**28.05%**	23
Total		**82**

Q9 When using a VR HMD, I experience anxiety regarding my inability to tell what is happening around me (e.g. someone has entered the room, what they are doing, whether they are watching me)?

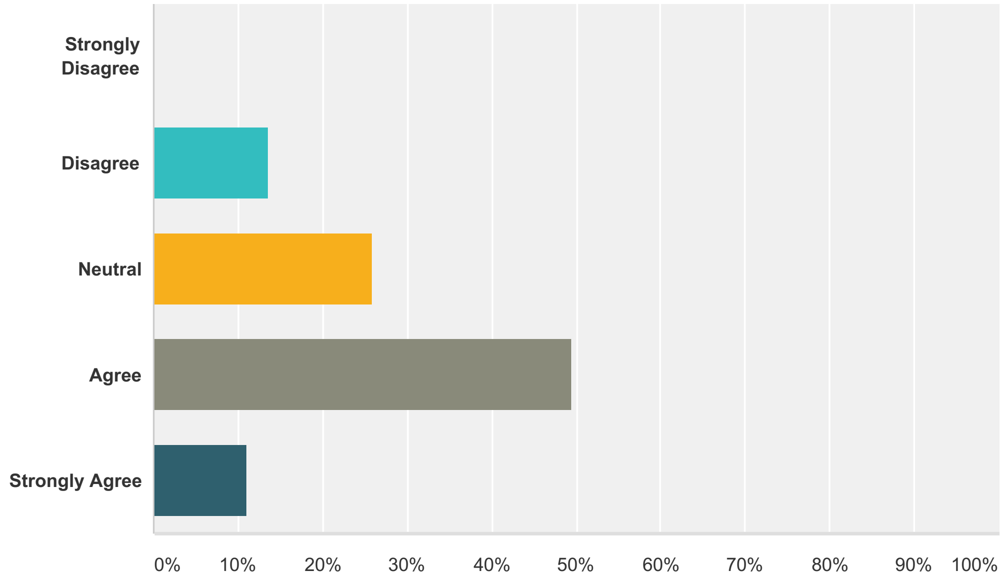
Answered: 81 Skipped: 37



Answer Choices	Responses	
Strongly Disagree	30.86%	25
Disagree	34.57%	28
Neutral	12.35%	10
Agree	16.05%	13
Strongly Agree	6.17%	5
Total		81

Q10 My level of awareness of reality when using a VR HMD is enough that i feel comfortable and secure in my personal surroundings

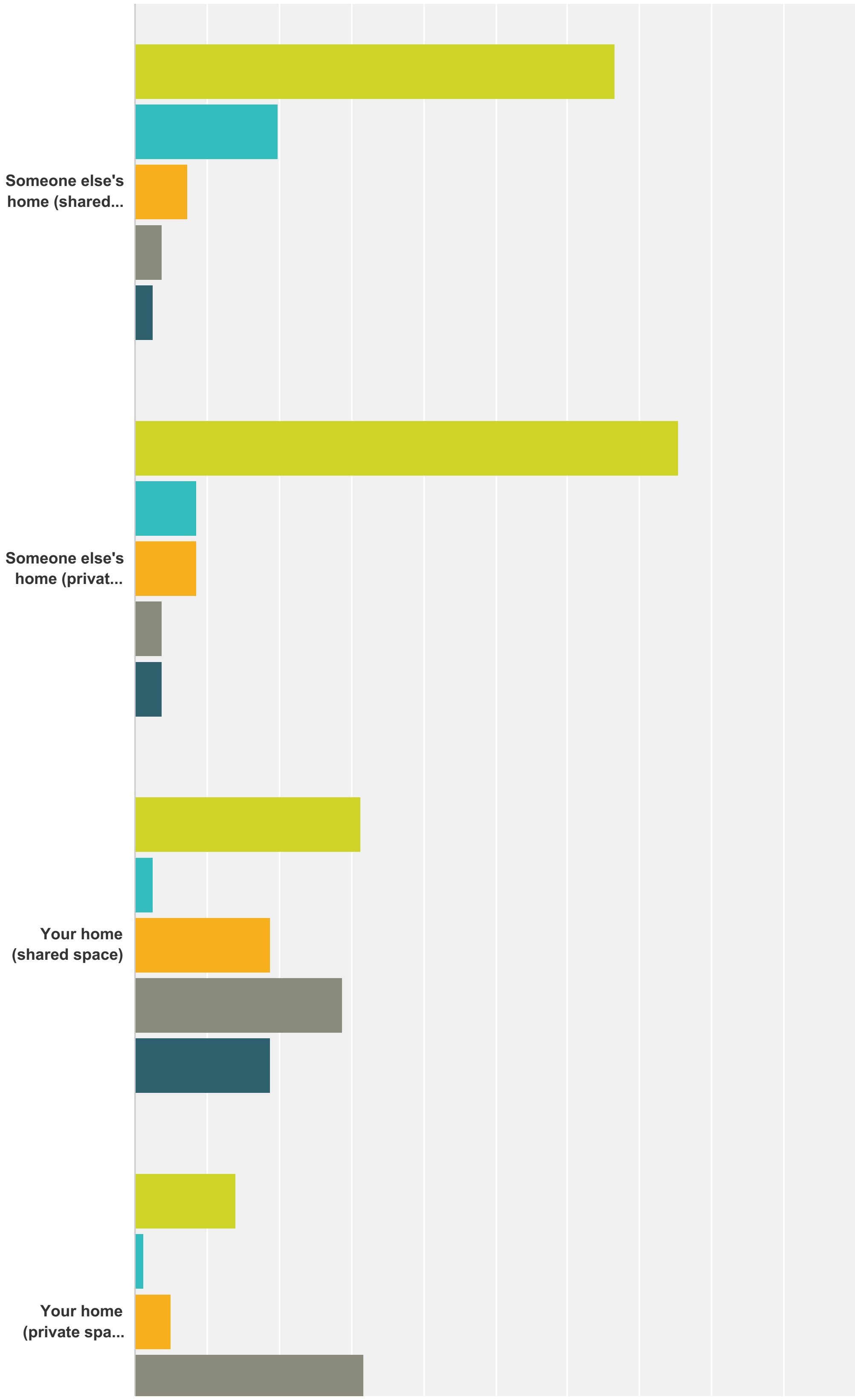
Answered: 81 Skipped: 37

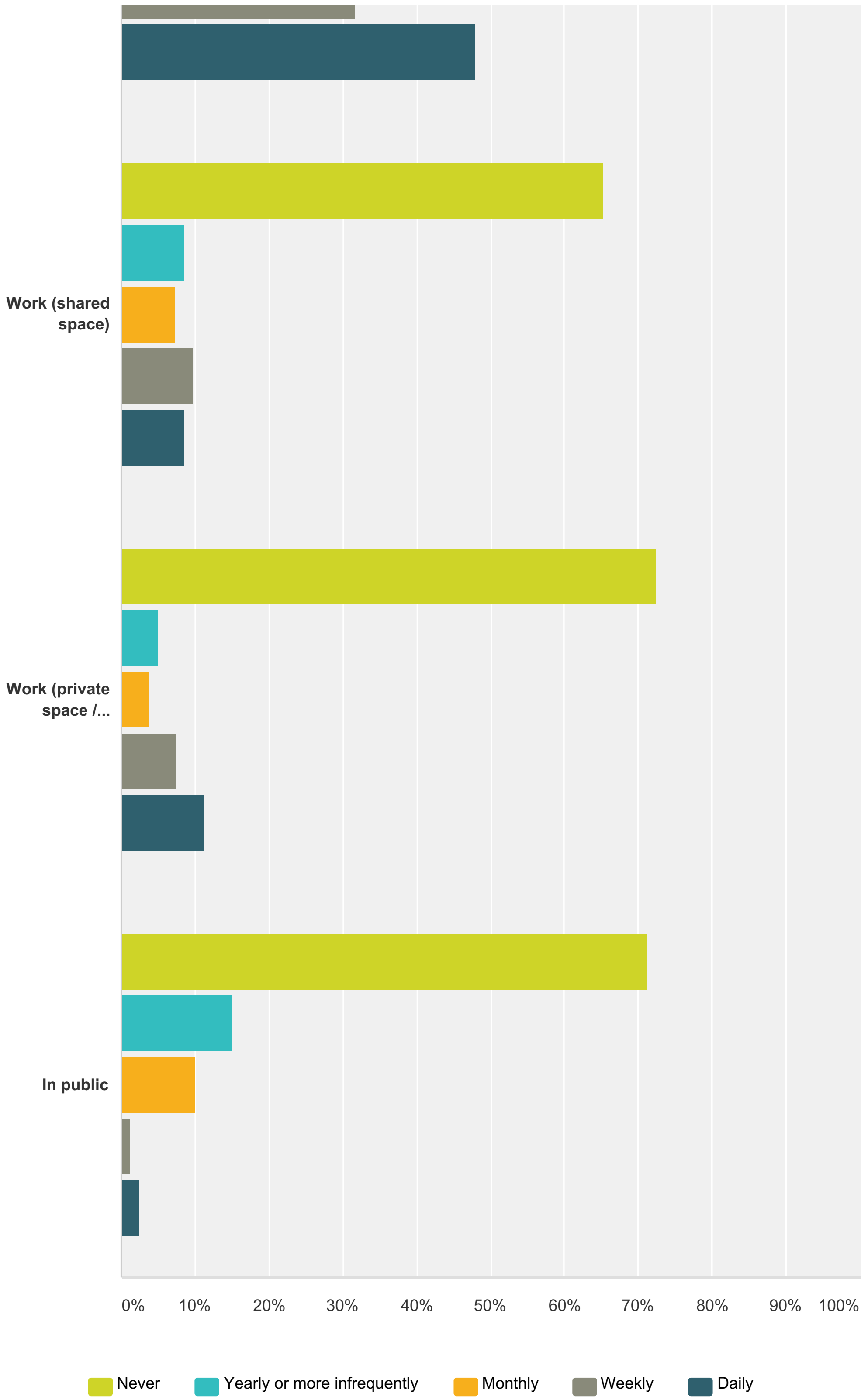


Answer Choices	Responses	
Strongly Disagree	**0.00%**	0
Disagree	**13.58%**	11
Neutral	**25.93%**	21
Agree	**49.38%**	40
Strongly Agree	**11.11%**	9
Total		**81**

Q11 In what settings do you use a VR HMD, and how frequently?

Answered: 82 Skipped: 36



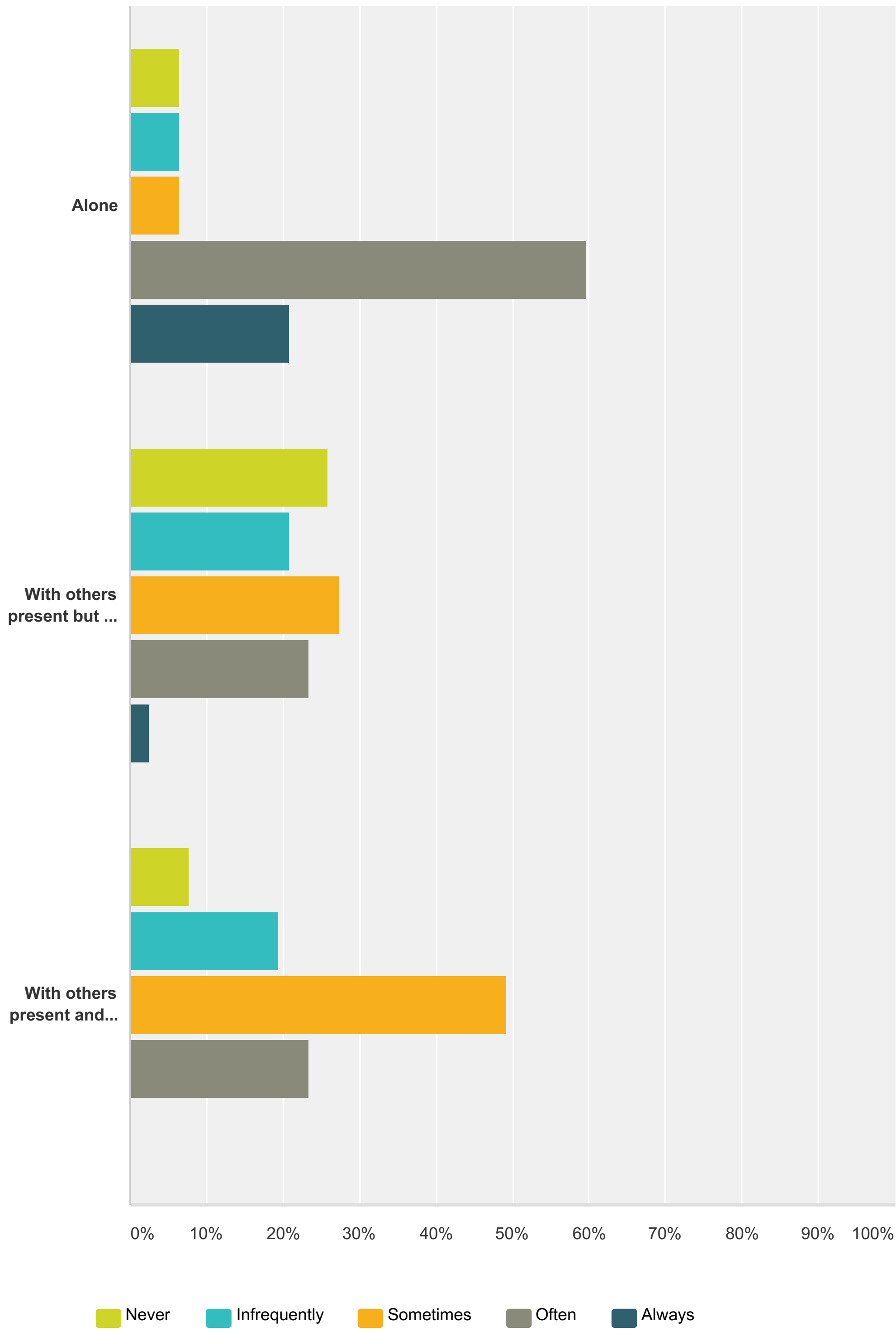


	Never	Yearly or more infrequently	Monthly	Weekly	Daily	Total
Someone else's home (shared space)	**66.67%** 54	**19.75%** 16	**7.41%** 6	**3.70%** 3	**2.47%** 2	81

Someone else's home (private space / predominantly alone)	**75.31%** 61	**8.64%** 7	**8.64%** 7	**3.70%** 3	**3.70%** 3	81
Your home (shared space)	**31.25%** 25	**2.50%** 2	**18.75%** 15	**28.75%** 23	**18.75%** 15	80
Your home (private space / predominantly alone)	**13.92%** 11	**1.27%** 1	**5.06%** 4	**31.65%** 25	**48.10%** 38	79
Work (shared space)	**65.43%** 53	**8.64%** 7	**7.41%** 6	**9.88%** 8	**8.64%** 7	81
Work (private space / predominantly alone)	**72.50%** 58	**5.00%** 4	**3.75%** 3	**7.50%** 6	**11.25%** 9	80
In public	**71.25%** 57	**15.00%** 12	**10.00%** 8	**1.25%** 1	**2.50%** 2	80

Q12 How often do you use VR HMD in the following contexts?

Answered: 77   Skipped: 41

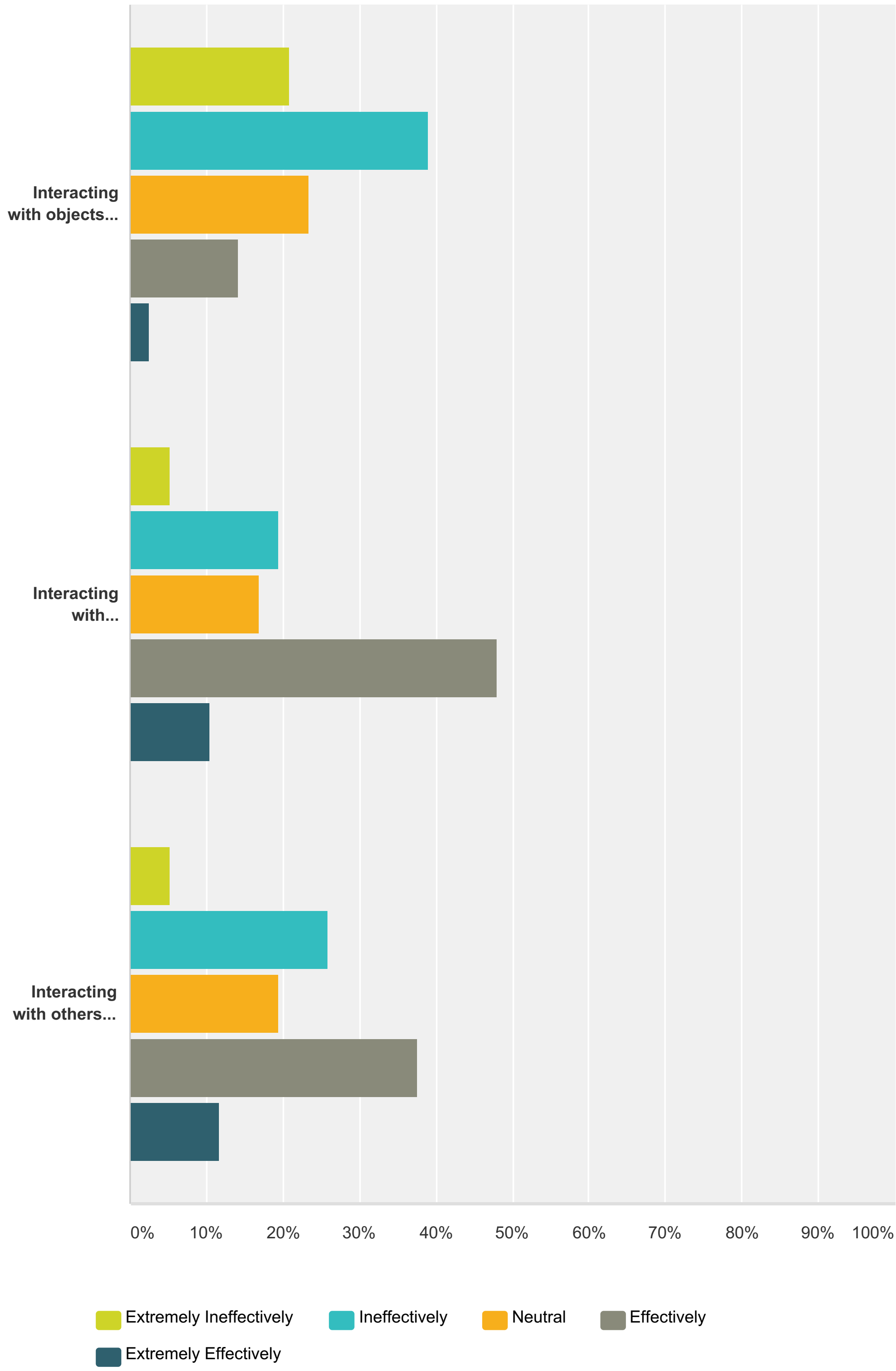


	Never	Infrequently	Sometimes	Often	Always	Total

Alone	**6.49%** 5	**6.49%** 5	**6.49%** 5	**59.74%** 46	**20.78%** 16	77
With others present but not observing your actions	**25.97%** 20	**20.78%** 16	**27.27%** 21	**23.38%** 18	**2.60%** 2	77
With others present and observing your actions	**7.79%** 6	**19.48%** 15	**49.35%** 38	**23.38%** 18	**0.00%** 0	77

Q13 How effectively do you interact with the real world when wearing a VR HMD in the following contexts:

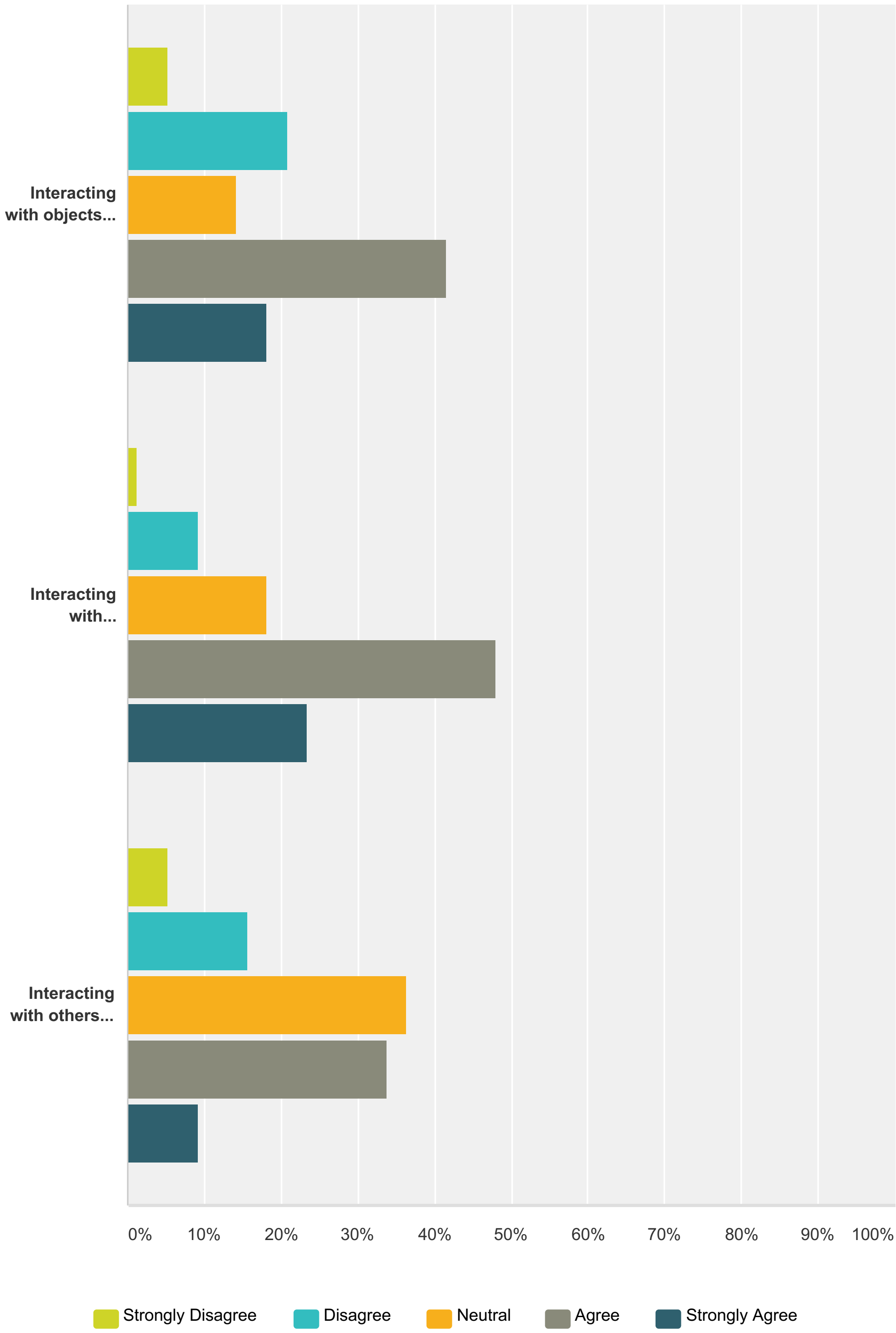
Answered: 77 Skipped: 41



	Extremely Ineffectively	Ineffectively	Neutral	Effectively	Extremely Effectively	Total
Interacting with objects (e.g. a cup)	**20.78%** 16	**38.96%** 30	**23.38%** 18	**14.29%** 11	**2.60%** 2	77
Interacting with peripherals (e.g. keyboard, pen input, flight controls etc.)	**5.19%** 4	**19.48%** 15	**16.88%** 13	**48.05%** 37	**10.39%** 8	77
Interacting with others (e.g. talking to friends)	**5.19%** 4	**25.97%** 20	**19.48%** 15	**37.66%** 29	**11.69%** 9	77

Q14 Do you agree that VR HMDs should provide ways of enabling easier interaction (e.g. seeing / hearing) with the following:

Answered: 77 Skipped: 41

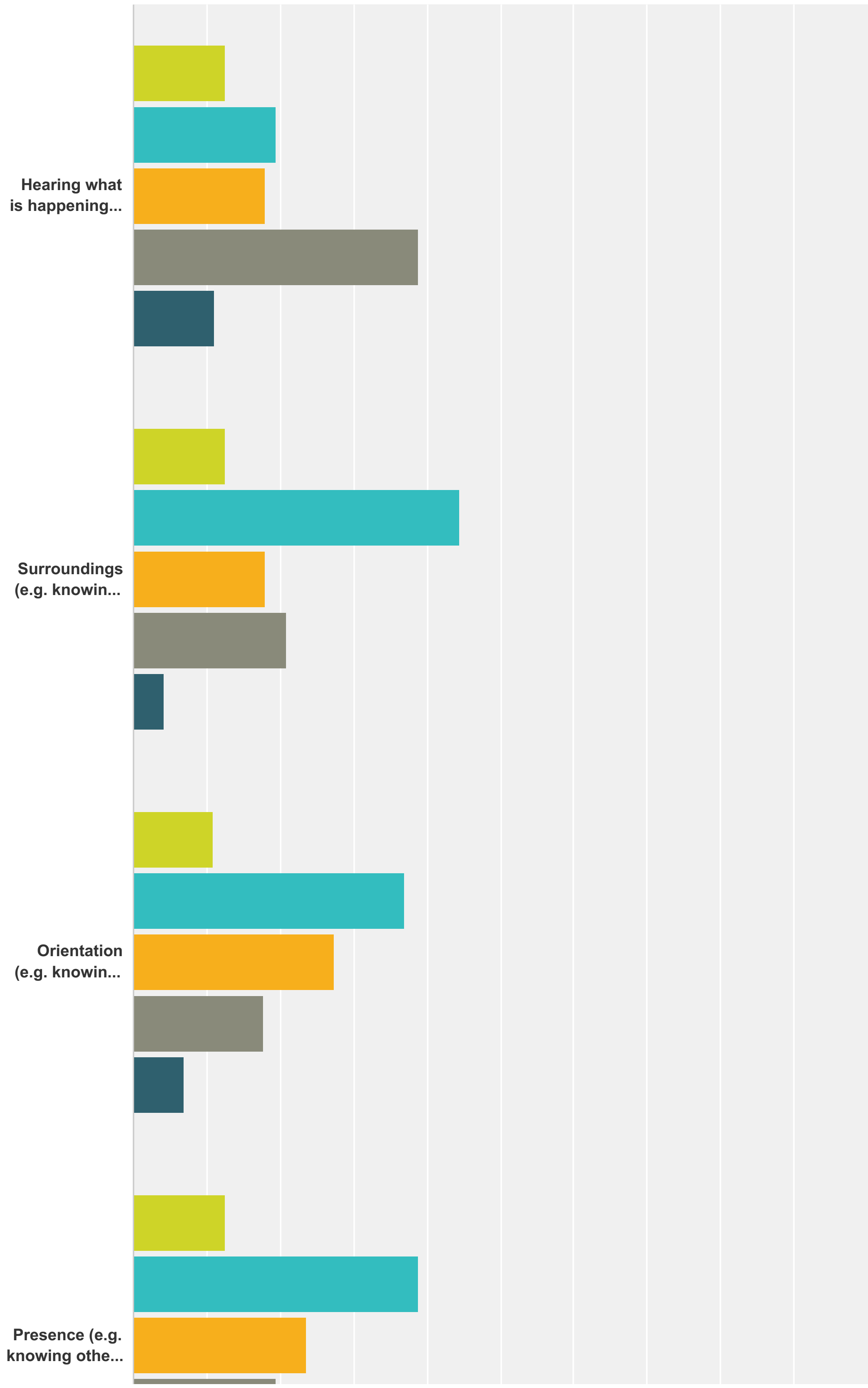


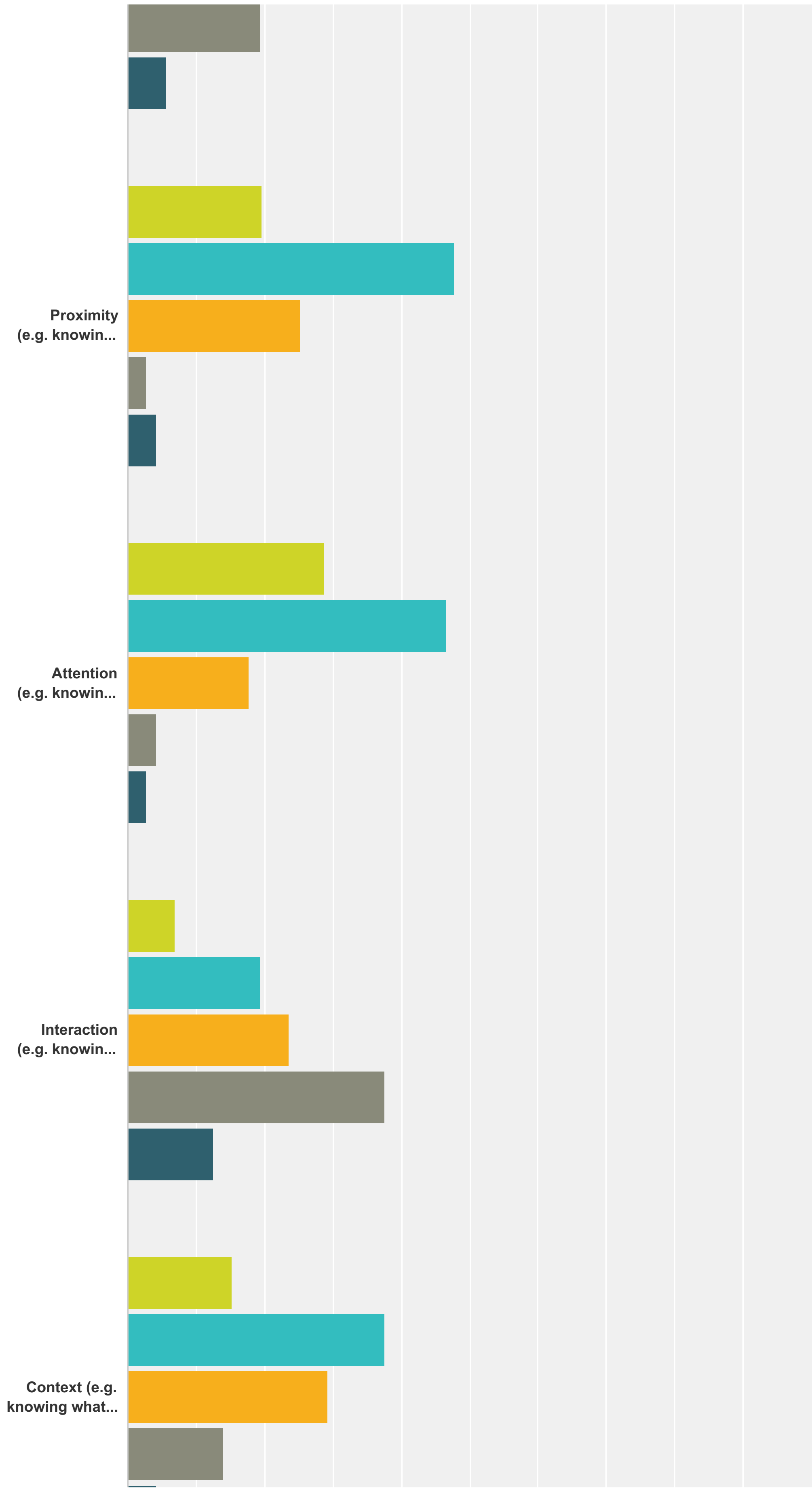
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Total

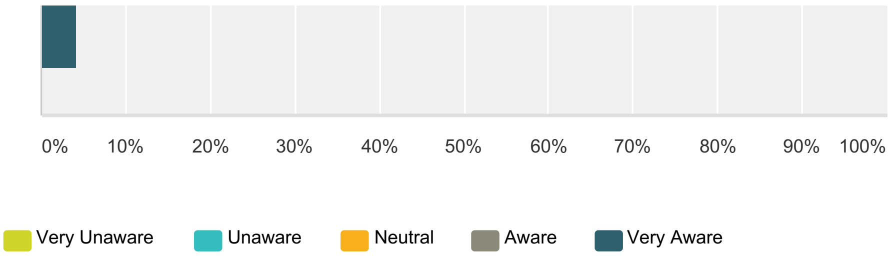
Interacting with objects (e.g. a cup)	**5.19%** 4	**20.78%** 16	**14.29%** 11	**41.56%** 32	**18.18%** 14	77
Interacting with peripherals (e.g. keyboard, pen input, flight controls etc.)	**1.30%** 1	**9.09%** 7	**18.18%** 14	**48.05%** 37	**23.38%** 18	77
Interacting with others (e.g. talking to friends)	**5.19%** 4	**15.58%** 12	**36.36%** 28	**33.77%** 26	**9.09%** 7	77

Q15 To what extent are you aware of the following aspects of the real world when wearing a VR HMD?

Answered: 73   Skipped: 45



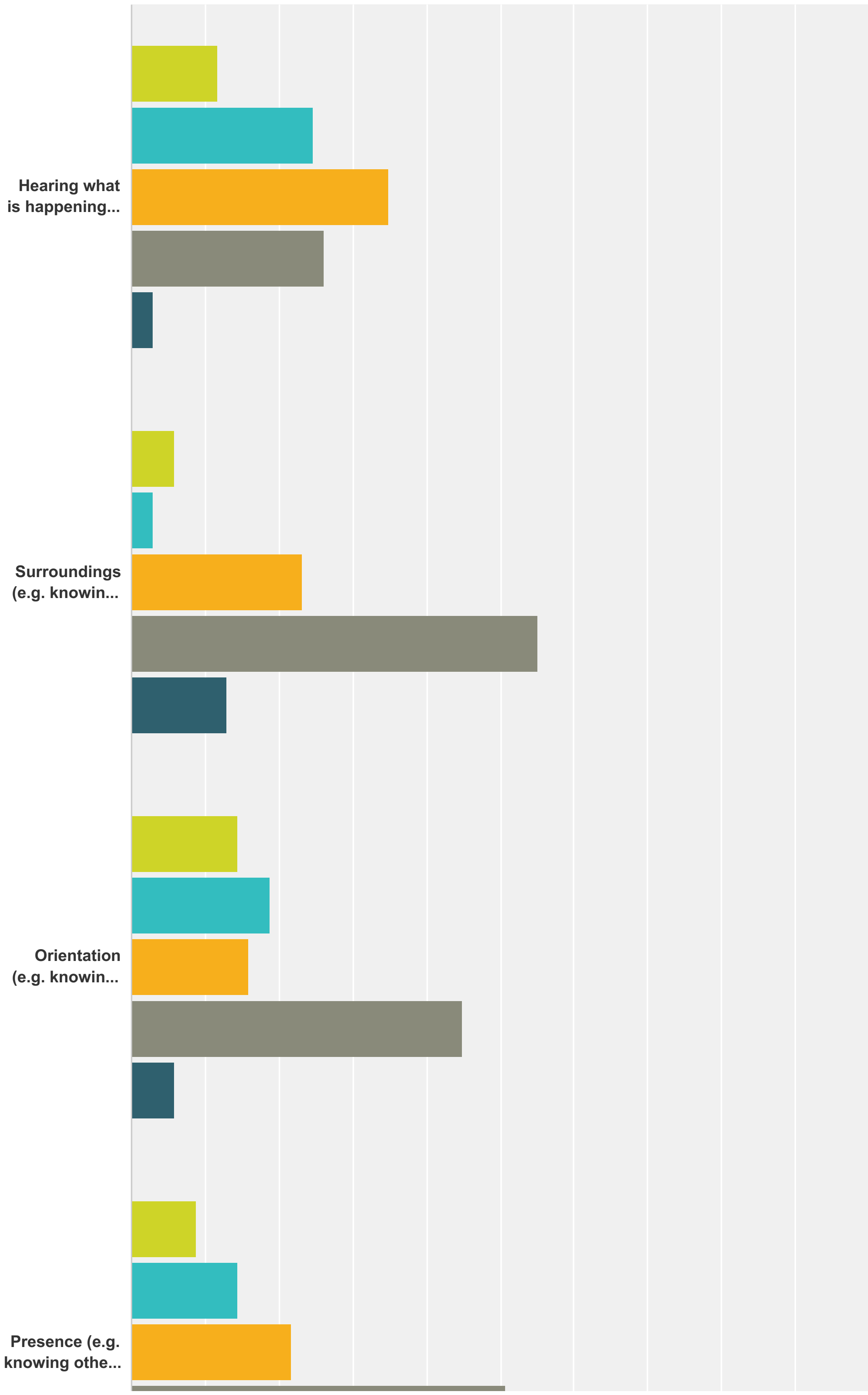

Proximity
(e.g. knowin...
Attention
(e.g. knowin...
Interaction
(e.g. knowin...
Context (e.g.
knowing what...

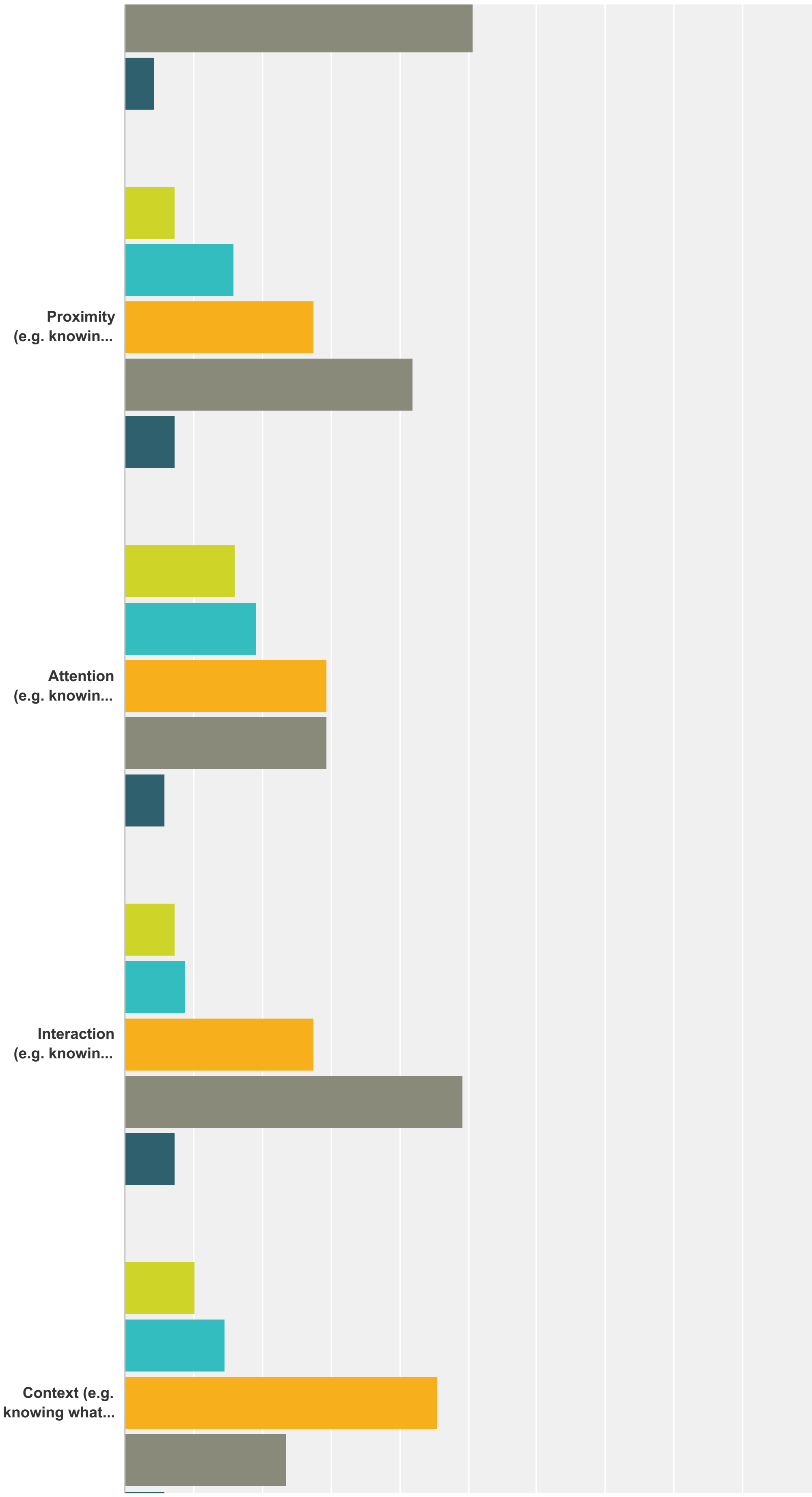


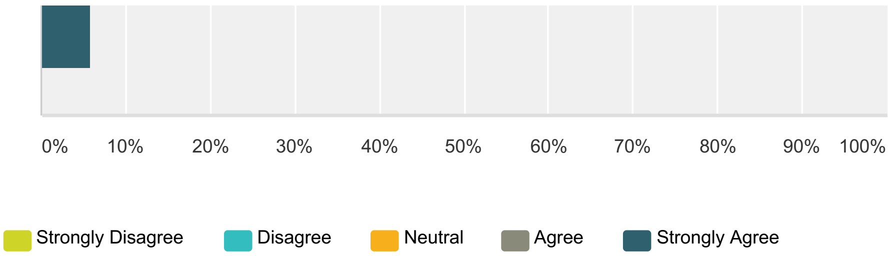
	Very Unaware	Unaware	Neutral	Aware	Very Aware	Total
Hearing what is happening in the room (e.g. movement, talking)	**12.50%** 9	**19.44%** 14	**18.06%** 13	**38.89%** 28	**11.11%** 8	72
Surroundings (e.g. knowing you are close to a wall)	**12.50%** 9	**44.44%** 32	**18.06%** 13	**20.83%** 15	**4.17%** 3	72
Orientation (e.g. knowing spatially where you are in the room and where you are facing)	**10.96%** 8	**36.99%** 27	**27.40%** 20	**17.81%** 13	**6.85%** 5	73
Presence (e.g. knowing others have entered the room)	**12.50%** 9	**38.89%** 28	**23.61%** 17	**19.44%** 14	**5.56%** 4	72
Proximity (e.g. knowing how close others are to you)	**19.72%** 14	**47.89%** 34	**25.35%** 18	**2.82%** 2	**4.23%** 3	71
Attention (e.g. knowing if you are being observed)	**28.77%** 21	**46.58%** 34	**17.81%** 13	**4.11%** 3	**2.74%** 2	73
Interaction (e.g. knowing someone is trying to talk to you)	**6.94%** 5	**19.44%** 14	**23.61%** 17	**37.50%** 27	**12.50%** 9	72
Context (e.g. knowing what is happening around you)	**15.28%** 11	**37.50%** 27	**29.17%** 21	**13.89%** 10	**4.17%** 3	72

Q16 Do you agree that VR HMDs should provide ways of enabling the following types of awareness:

Answered: 69   Skipped: 49



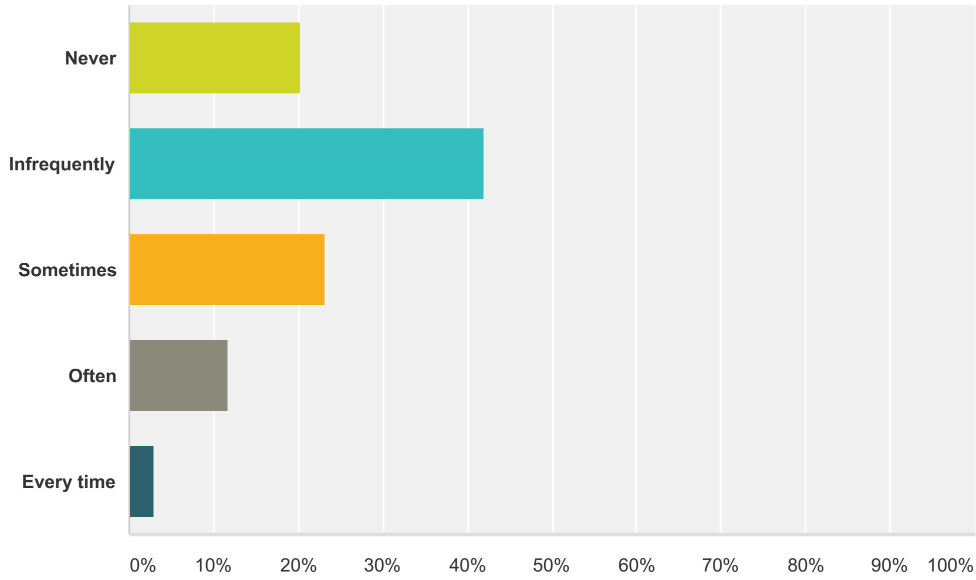

Proximity
(e.g. knowin...
Attention
(e.g. knowin...
Interaction
(e.g. knowin...
Context (e.g.
knowing what...



	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Total
Hearing what is happening in the room (e.g. movement, talking)	**11.59%** 8	**24.64%** 17	**34.78%** 24	**26.09%** 18	**2.90%** 2	69
Surroundings (e.g. knowing you are close to a wall)	**5.80%** 4	**2.90%** 2	**23.19%** 16	**55.07%** 38	**13.04%** 9	69
Orientation (e.g. knowing spatially where you are in the room and where you are facing)	**14.49%** 10	**18.84%** 13	**15.94%** 11	**44.93%** 31	**5.80%** 4	69
Presence (e.g. knowing others have entered the room)	**8.70%** 6	**14.49%** 10	**21.74%** 15	**50.72%** 35	**4.35%** 3	69
Proximity (e.g. knowing how close others are to you)	**7.25%** 5	**15.94%** 11	**27.54%** 19	**42.03%** 29	**7.25%** 5	69
Attention (e.g. knowing if you are being observed)	**16.18%** 11	**19.12%** 13	**29.41%** 20	**29.41%** 20	**5.88%** 4	68
Interaction (e.g. knowing someone is trying to talk to you)	**7.25%** 5	**8.70%** 6	**27.54%** 19	**49.28%** 34	**7.25%** 5	69
Context (e.g. knowing what is happening around you)	**10.29%** 7	**14.71%** 10	**45.59%** 31	**23.53%** 16	**5.88%** 4	68

Q17 How often do you feel symptoms of sickness or nausea from using the VR HMD?

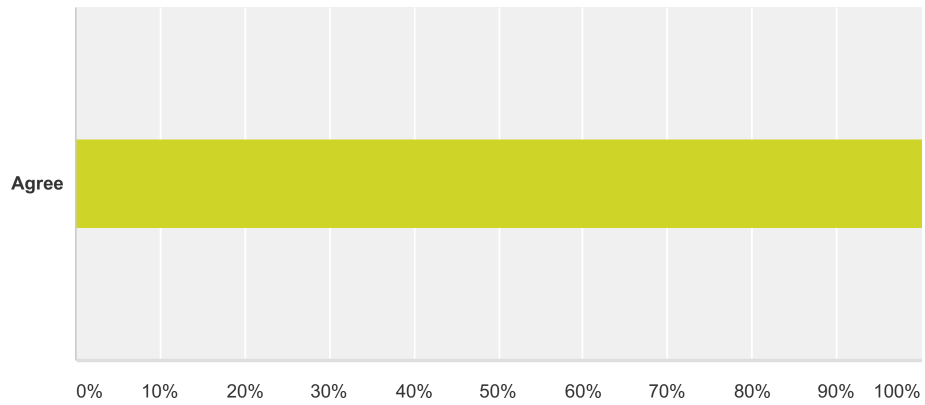
Answered: 69   Skipped: 49



Answer Choices	Responses	
Never	20.29%	14
Infrequently	42.03%	29
Sometimes	23.19%	16
Often	11.59%	8
Every time	2.90%	2
Total		69

Q18 Optional. If you use VR HMD, if possible can you please email a picture of the setting you typically use your VR HMD in (e.g. desk, living room on couch etc.) to m.mcgill.1@research.gla.ac.uk . Please check the following box if you are willing to allow us to use this picture in a publication (with any identifiable personal details blurred), illustrating the breadth of contexts in which VR HMD are used. Please note that only you may be present in the photo, as we are unable to acquire consent for others outside this survey, however it is not necessary for you to be in the photo.

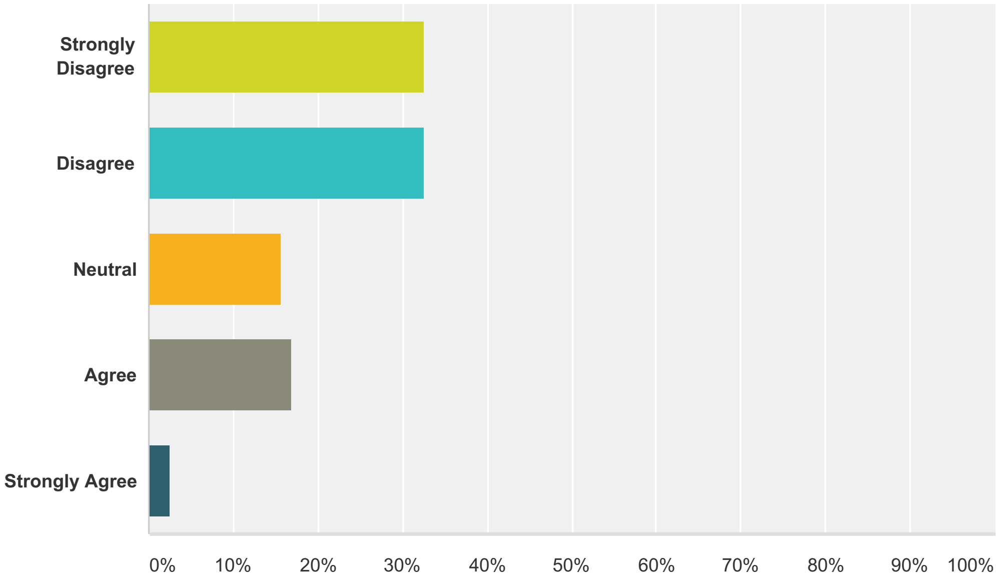
Answered: 23 Skipped: 95



Answer Choices	Responses	
Agree	100.00%	23
Total		23

Q19 Wearing a VR HMD with headphones removes your ability to perceive the real world, impacting your ability to interact with your surroundings or others present. Do you consider this to be a barrier toward your adoption and usage of VR HMDs?

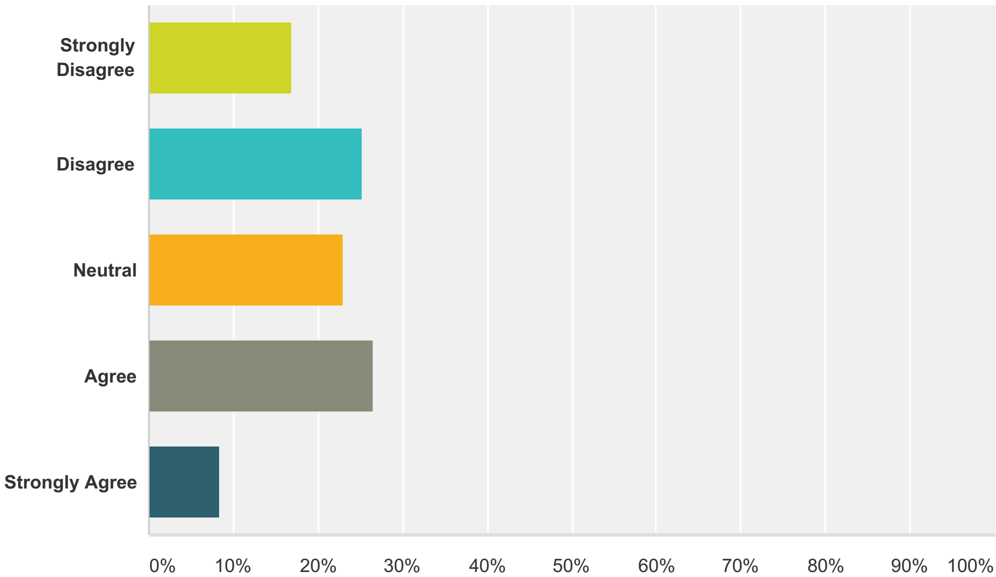
Answered: 83 Skipped: 35



Answer Choices	Responses	
Strongly Disagree	**32.53%**	27
Disagree	**32.53%**	27
Neutral	**15.66%**	13
Agree	**16.87%**	14
Strongly Agree	**2.41%**	2
Total		**83**

Q20 The lack of awareness regarding who is nearby or what is happening around me would be concerning.

Answered: 83   Skipped: 35



Answer Choices	Responses	
Strongly Disagree	**16.87%**	14
Disagree	**25.30%**	21
Neutral	**22.89%**	19
Agree	**26.51%**	22
Strongly Agree	**8.43%**	7
Total		**83**

Q21 Demographics (email address required to enter draw)

Answered: 62 Skipped: 56

Answer Choices	Responses	
Name:	0.00%	0
Company:	0.00%	0
Address 1:	0.00%	0
Address 2:	0.00%	0
City/Town:	0.00%	0
State/Province:	0.00%	0
ZIP/Postal Code:	0.00%	0
Country:	100.00%	62
Email Address:	77.42%	48
Phone Number:	0.00%	0

K. EXPERIMENT 7 MATERIALS

Participants in Experiment 7 (Chapter 7) were asked the following questions:

IPQ-INV1 How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?

IPQ-REAL1 How real did the virtual world seem to you?

IPQ-SP4 I had a sense of acting in the virtual space, rather than operating something from outside.

IPQ-REAL2 How much did your experience in the virtual environment seem consistent with your real world experience?

IPQ-REAL3 How real did the virtual world seem to you?

IPQ-SP3 I did not feel present in the virtual space.

IPQ-INV2 I was not aware of my real environment.

IPQ-G1 In the computer generated world I had a sense of being there

IPQ-SP1 Somehow I felt that the virtual world surrounded me.

IPQ-SP5 I felt present in the virtual space.

IPQ-INV3 I still paid attention to the real environment.

IPQ-REAL4 The virtual world seemed more realistic than the real world.

IPQ-SP2 I felt like I was just perceiving pictures.

IPQ-INV4 I was completely captivated by the virtual world.

TPI Passive Interpersonal During the media experience how well were you able to observe the facial expressions of the people you saw/heard?

TPI Passive Interpersonal During the media experience how well were you able to observe the style of dress of the people you saw/heard?

TPI Passive Interpersonal During the media experience how well were you able to observe the body language of the people you saw/heard?

DIST Please rate how distracting you found reality in this virtual reality experience

Awareness How aware were you of the presence of others?

Comfort How comfortable did you feel with regards to your personal space?

The plain language statement given to participants follows.

University of Glasgow

Plain Language Statement

1. Study title and Researcher Details

Cast Away - TV at-a-distance

Researcher: Mark McGill m.mcgill.1@research.gla.ac.uk (PhD Student 0303456)
Supervisor: Professor Stephen Brewster Stephen.Brewster@glasgow.ac.uk

IMPORTANT

In order to take part in this study, you must be aged 18 or over, have access to a TV with HDMI port, and an unlimited high-speed broadband connection, and suffer no visual or auditory impairments (i.e. you are able to take part in a video call). You will need to provide a partner with which to conduct the study, who will also need to read this document and reply to the associated consent form in order to take part. You must both reside in the UK.

2. Invitation paragraph

You are being invited to take part in a paid study, which should take approximately **1 week** to complete. Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Take time to decide whether or not you wish to take part.

If there is anything that is unclear, or you would like more information, or you have any questions, please feel free to raise these concerns with the researcher present. If you wish to discuss any aspect of this study at a later date, contact us at the email addresses listed above. Alternatively, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at the following email address: Peter.Uhlhaas@glasgow.ac.uk

3. What is the purpose of the study?

The purpose of this study is to investigate at-a-distance shared TV experiences. By “at-a-distance shared TV experiences”, we are referring to the capability to have the TVs in multiple places synchronized, such that if a programme plays on one, it also plays on the other. For this study, we will be using smartphone devices that support Google Chromecast, allowing for a selection of applications (BBC iPlayer, Google Play Music) to have their content sent to multiple TVs at once across any distance (within the UK).

In this study, pairs of participants that know each other will be given a complete system for at-a-distance TV usage, allowing them to initiate shared Chromecast sessions, and cast content to both TVs at the same time. Additionally the smartphones provided will be equipped with software to allow participants to communicate with each other, be it textual, speech, or video communications.

4. Why have I been chosen?

Your participation has been solicited through emails or notice board postings to which you replied, and you have indicated you are in a long distance relationship of some form (be it having a partner, friend, or family residing in another household to which you currently reside).

5. Do I have to take part?

Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

6. What will happen to me if I take part?

You will be asked to use the provided system over the course of a week, watching and listening to content with your partner at-a-distance (i.e. when in different households in the UK) and using the communications facilities provided if you wish to communicate with your partner during these sessions.

Your activity on the smartphone will be logged and recorded. Your communications activity will also be logged in a limited form:

- Text chats will be logged in terms of length (number of words, number of characters), when typing started, when messages were sent, but **not** content.
- Voice chats will be logged in terms of when this functionality was turned on/off. They **will additionally be recorded on the device**, for future automated analysis in order to determine how much vocal communication occurred.
    - This data will be listened to by the experimenter in a limited capacity i.e. listening to the first 20 seconds of a recording for calibration purposes, after which the speech will be automatically analysed. **This data will reside on the device until the device is returned to the experimenter, meaning that you can review this recorded speech data, and delete recordings if you so wish.**
- Video data will be logged in terms of when this functionality was turned on/off but **not** content.

Throughout the course of the study you will periodically be interviewed and asked to complete questionnaires regarding your usage of the system, and the effect it is having on your relationship with your partner. At the end of the study you will then be debriefed and asked to answer some questions to help us better understand the experience you have undertaken. For taking part, you will be paid £50.

7. Will my taking part in this study be kept confidential?

Yes, all data collected from you will be treated confidentially, will be seen in its raw form only by the experimenters, and if published will not be identifiable as coming from you. Please do not to log in to any personalized web services on the devices provided whilst taking part in the experiment, as all content entered will be recorded.

8. What will happen to the results of the research study?

The results of the study may appear in a Doctoral thesis, and a number of published studies, again all in a confidential format where anonymity is preserved.

9. Who is organising and funding the research?

This project is part of an industrial studentship PhD part sponsored by Bang & Olufsen, being conducted at the University of Glasgow.

10. Who has reviewed the study?

This study adheres to the BPS ethical guidelines, and has been approved by the College of Science and Engineering ethics committee of The University of Glasgow (ref: D1437554107627).

11. Contact for Further Information

Whilst you are free to discuss your participation in this study with the researcher, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at Peter.Uhlhaas@glasgow.ac.uk

For further information, or if you wish to receive a summary of the findings of this experiment at a later date, please contact the researcher or the supervisor of this project, details listed below.

Researcher - Mark McGill
Email: m.mcgill.1@research.gla.ac.uk
Tel: 07791201325
Address: Room F122
17 Lilybank Gardens
Glasgow, G12 8RZ, UK

Supervisor - Professor Stephen Brewster
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L. Experiment 8 Materials

This questionnaire was delivered at the end of each Condition in the VR at-a-distance study (Chapter 8).

Plain Language Statement

1. Study title and Researcher Details

Reality In Virtuality Study (School of Computing Science)

Researchers: Mark McGill m.mcgill.1@research.gla.ac.uk (PhD Student)
Daniel Boland daniel@dcs.gla.ac.uk (PhD Student)
Supervisor: Professor Stephen Brewster Stephen.Brewster@glasgow.ac.uk

IMPORTANT
In order to take part in this study, you must meet the following requirements:

1. Aged 18 or over
2. **No history** (personal and family) **of epileptic seizures, strokes, or photosensitivity**
3. **Not a member of any of the following groups**
   a. Pregnant women
   b. The elderly
   c. Sufferers of serious medical conditions
   d. Sleep deprived
   e. Under the influence of alcohol
   f. Sufferers of motion sickness
   g. Sufferers of visual disorders
4. Be comfortable with wearing a headset: straps will be partially covering your head, and your view will be enclosed by a head mounted virtual reality display
5. Be able to type using a standard keyboard

2. Invitation paragraph

You are being invited to take part in a paid study, which should take approximately 1 hour 15 minutes to complete. Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Take time to decide whether or not you wish to take part.

If there is anything that is unclear, or you would like more information, or you have any questions, please feel free to raise these concerns with the researcher present. If you wish to discuss any aspect of this study at a later date, contact us at the email addresses listed above. Alternatively, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at the following email address: Christoph.Scheepers@glasgow.ac.uk

3. What is the purpose of the study?

The purpose of this study is to investigate the potential for selectively revealing elements of reality in virtual reality displays, with the aim of enabling better use of these virtual reality displays in home and office environments.

For this study, we will be using an Oculus Rift head mounted virtual reality display.

4. Why have I been chosen?

Your participation has been solicited through emails or notice board postings to which you replied.

5. Do I have to take part?

Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

6. What will happen to me if I take part?

Firstly, you will be fitted with the head mounted display (HMD) such that it sits comfortably on your head, and you can see the virtual view correctly.

You will then be led through two separate tasks, each evaluating a different element of usage.

The first will be a typing task, where you will be asked to type given sentences out using a standard consumer keyboard. Your view of the keyboard will vary between normal usage (no HMD), VR usage (HMD), and VR usage with the view of the keyboard inserted into your virtual view.

The second task will be to watch given media in virtual reality whilst trialling different methods of revealing the activity of other people in the room, in order to determine the effect this has on your immersion and sense of presence in virtuality.

You will then be debriefed and asked to answer some questions to help us better understand the acceptability of the experience you have undertaken. For taking part, you will be paid £8.

N.B. If you experience any of the following symptoms during this study, remove the head mounted display immediately and inform the researcher: (1) altered vision; (2) lightheadedness; (3) dizziness; (4) involuntary movements such as eye or muscle twitching; (5) confusion; (6) nausea; (7) loss of awareness; (8) convulsions; (9) cramps; (10) disorientation; (11) motion sickness; (12) Discomfort or pain in head or eyes; (13) Any other symptoms that you would class as atypical or unusual.

7. Will my taking part in this study be kept confidential?

Yes, all data collected from you will be treated confidentially, will be seen in its raw form only by the experimenters, and if published will not be identifiable as coming from you. You will be reminded not to log in to any personalized web services on the devices provided whilst taking part in the experiment, as all content entered will be recorded.

8. What will happen to the results of the research study?

The results of the study may appear in a Doctoral thesis, and a number of published studies, again all in a confidential format where anonymity is preserved.

9. Who is organising and funding the research?

This project is part of an industrial studentship PhD part sponsored by Bang & Olufsen, being conducted at the University of Glasgow.

10. Who has reviewed the study?

This study adheres to the BPS ethical guidelines, and has been approved by the College of Science and Engineering ethics committee of The University of Glasgow (ref: CSEXXXX).

11. Contact for Further Information

Whilst you are free to discuss your participation in this study with the researcher, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at Christoph.Scheepers@glasgow.ac.uk

For further information, or if you wish to receive a summary of the findings of this experiment at a later date, please contact the researcher or the supervisor of this project, details listed below.

Researcher
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17 Lilybank Gardens
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Supervisor
Professor Stephen Brewster
Email: Stephen.Brewster@glasgow.ac.uk
Tel: +44 (0)141 330 4966

Debrief

Thanks for taking part in the "Reality In Virtuality" experiment! If there are any questions or issues, or if you wish to receive a summary of the findings of this experiment at a later date, please say to the researcher now, or optionally contact the researcher or the supervisor of this project at a later date, details listed below.

Researchers
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Tel: +44 (0)141 330 4966

Whilst you are free to discuss your participation in this study with the researcher, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at Christoph.Scheepers@glasgow.ac.uk

Survey Sheet (on completion)

General information

Name:

Email Address:

Age: **Gender**: male / female

I consent to being contacted for related follow up studies (tick if you agree): □

The plain language statement given to participants follows.

Plain Language Statement

1. Study title and Researcher Details

VR at-a-distance (School of Computing Science) - D1437729983719

Researchers: Mark McGill m.mcgill.1@research.gla.ac.uk (PhD Student)
Supervisor: Professor Stephen Brewster Stephen.Brewster@glasgow.ac.uk

IMPORTANT
In order to take part in this study, you must meet the following requirements:

1. Aged 18 or over
2. **No history** (personal and family) **of epileptic seizures, strokes, or photosensitivity**
3. **Not a member of any of the following groups**
    a. Pregnant women
    b. The elderly
    c. Sufferers of serious medical conditions
    d. Sleep deprived
    e. Under the influence of alcohol
    f. Sufferers of motion sickness
    g. Sufferers of visual disorders
4. Be comfortable with wearing a headset: straps will be partially covering your head, and your view will be enclosed by a head mounted virtual reality display

2. Invitation paragraph

You are being invited to take part in a paid study, which should take approximately 1 hour 20-30 minutes to complete. Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Take time to decide whether or not you wish to take part.

If there is anything that is unclear, or you would like more information, or you have any questions, please feel free to raise these concerns with the researcher present. If you wish to discuss any aspect of this study at a later date, contact us at the email addresses listed above. Alternatively, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at the following email address: Peter.Uhlhaas@glasgow.ac.uk

3. What is the purpose of the study?

The purpose of this study is to examine the extent to which Virtual Reality Head-Mounted Displays (VR HMD) might supplant the combination of TV with computer mediated communication for synchronous, at-a-distance experiences. Currently, it is typical for couples in long distance relationships to use technology to enjoy shared experiences at a distance, for example watching a film together via Netflix whilst communicating via Skype. We wish to examine how VR displays might change the nature of these experiences, by providing not only shared experiences, but shared spaces, and fully embodied communication.

For this study, we will be using Oculus Rift head mounted virtual reality displays, which will allow you to share a virtual space with your partner participant.

4. Why have I been chosen?

Your participation has been solicited through emails or notice board postings to which you replied.

5. Do I have to take part?

Your participation is voluntary, and you are free to withdraw at any time, without giving any reason, and you are free to omit answering any particular question, without providing a reason.

6. What will happen to me if I take part?

Firstly, you will be fitted with the head mounted display (HMD) such that it sits comfortably on your head, and you can see the virtual view correctly.

You will then undergo five different conditions, examining different aspects of synchronous media consumption:

a. TV Together, sitting side-by-side

b. TV at-a-distance, viewing silhouette of partner on TV

c. VR TV at-a-distance, watching TV in the same room in VR

d. Immersive VR TV, watching TV in a VR cinema

e. Immersive VR, watching a 360 degree VR experience

In all the conditions, you will be able to communicate with your partner in varying ways, namely through speech audio and either a video feed of your partner, or through being able to see your partner in virtual reality sitting alongside you, or being able to see your partner in person. You will also be wearing headphones with microphones throughout the study.

For each condition, you will watch a 10 minute video clip of a documentary programme together at-a-distance, and will be free to communicate using the given medium for each condition. Your conversations will not be recorded. Your actions will however be recorded in a limited away (the amount you speak, and where you look in the VR conditions). After each condition you will answer a series of questions on your experience.

You will then be debriefed and asked to answer some questions to help us better understand the experience you have undertaken. For taking part, you will be paid £12.

N.B. If you experience any of the following symptoms during this study, remove the head mounted display immediately and inform the researcher: (1) altered vision; (2) lightheadedness; (3) dizziness; (4) involuntary movements such as eye or muscle twitching; (5) confusion; (6) nausea; (7) loss of awareness; (8) convulsions; (9) cramps; (10) disorientation; (11) motion sickness; (12) Discomfort or pain in head or eyes; (13) Any other symptoms that you would class as atypical or unusual.

7. Will my taking part in this study be kept confidential?

Yes, all data collected from you will be treated confidentially, will be seen in its raw form only by the experimenters, and if published will not be identifiable as coming from you.

8. What will happen to the results of the research study?

The results of the study may appear in a Doctoral thesis, and a number of published studies, again all in a confidential format where anonymity is preserved.

9. Who is organising and funding the research?

This project is part of an industrial studentship PhD part sponsored by Bang & Olufsen, being conducted at the University of Glasgow.

10. Who has reviewed the study?

This study adheres to the BPS ethical guidelines, and has been approved by the College of Science and Engineering ethics committee of The University of Glasgow (ref: *D1437729983719*).

11. Contact for Further Information

Whilst you are free to discuss your participation in this study with the researcher, if you would like to speak to someone not involved in the study, you may contact the Ethics Committee at Peter.Uhlhaas@glasgow.ac.uk

For further information, or if you wish to receive a summary of the findings of this experiment at a later date, please contact the researcher or the supervisor of this project, details listed below.

Researcher
Mark McGill
PhD Student 0303456
Email: m.mcgill.1@research.gla.ac.uk
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Supervisor
Professor Stephen Brewster
Email: Stephen.Brewster@glasgow.ac.uk
Tel: +44 (0)141 330 4966

University of Glasgow

Survey Sheet (on completion)

General information

Name:

Email Address:

Age: **Gender**: male / female

I consent to being contacted for related follow up studies (tick if you agree): □

Relation to other participant (tick all that apply)

Participant

□ Acquaintance □ Friend □ Brother/Sister □ Mother/Father □ Other family

□ Partner □ Cohabitant □ Lab/Project partner □ Spouse □ Work/University colleague

Have you used a VR headset before?

Frequently Occasionally Rarely Never

Rankings

If technical and cost constraints were removed, and you wanted to watch media content together with a partner at a distance, please rank the conditions in order of preference, from (1) most preferred to (4) least preferred.
(if you are uncertain which description is which condition, please inform the demonstrator)

____ TV at-a-distance, viewing silhouette of partner on TV

____ VR TV at-a-distance, watching traditional TV in the same room but in VR

____ VR TV at-a-distance, watching traditional TV in a VR cinema

____ VR at-a-distance, watching a 360 degree VR media experience

If technical and cost constraints were removed, and you wanted to watch media content alone, please rank the following in order of preference of use, from (1) most preferred to (3) least preferred.

____ 360 degree video in VR (e.g. the VR documentaries you witnessed today)

____ Standard TV content in a VR environment (e.g. a VR cinema)

____ Standard TV content on a TV in the real world

To what extent do you agree with the following statements:

If more people could be brought into the VR environment at a distance (e.g. watching content together with a number of friends or family), this would make me more likely to consume media in VR.

	1	2	3	4	5	6	7	
Strongly agree	○	○	○	○	○	○	○	Strongly disagree

Debrief

Thanks for taking part in the "VR at-a-distance" experiment! If there are any questions or issues, or if you wish to receive a summary of the findings of this experiment at a later date, please say to the researcher now, or optionally contact the researcher or the supervisor of this project at a later date, details listed below.

Researcher
Mark McGill
Email: m.mcgill.1@research.gla.ac.uk
Tel: 07791201325
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