Investigating the Impact of Cooperative Communication Mechanics on Player Performance in *Portal 2*

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ABSTRACT

Cooperative communication mechanics, such as avatar gestures or in-game visual pointers, enable player collaboration directly through gameplay. We currently lack a deeper understanding of how players use cooperative communication mechanics, and whether they can effectively supplement or even supplant traditional voice and chat communication. The present research investigated player communication in *Portal 2* by testing the game's native cooperative communication mechanics for dyads of players in custom test chambers. Following our initial hypothesis, players functioned best when they had access to both cooperative communication mechanics and voice. We found that players preferred voice communication, but perceived cooperative communication mechanics as necessary to coordinate interdependent actions.

Index Terms: H.5.3 [Information Systems]: Group and Organization Interfaces—Computer-supported cooperative work

1 INTRODUCTION

Over the past decade, we have seen an increase in the popularity of multi-player, non-collocated cooperative gameplay [24]. In these video games, teams play together while physically isolated from one another with the game acting as a collaborative virtual environment. To support team communication in these collaborative virtual environments, such games frequently provide not only voice communication [38], but also cooperative communication mechanics (CCMs) [33]. CCMs provide players a way to share ideas, in-game knowledge, and emotions with their fellow players by using the gameplay itself to communicate. Communication itself becomes a *core mechanic*, an activity that players explicitly invoke repeatedly in regular play, potentially with an opportunity cost of other in-game actions. So far, no research has investigated whether using CCMs are actually useful in comparison to traditional voice communication in games, though prior work has investigated effective design of CCMs (e.g., [40, 41]).

In this paper, we focus on understanding the effectiveness of CCMs in *Portal 2* [37], the cooperative-play mode of which features built-in CCMs: ping tools and avatar gestures. We hope to gain a better understanding of how CCMs are used and how they impact cooperative performance. In *Portal 2*, a dyad of players (i.e., a team of two) completes environmental puzzles from a first-person perspective, using a *portal gun* that fires *portals*: passages that allow the transition of the player between two points in the gameworld. We chose four custom-designed test chambers [36] for our study, crossed with four different communication conditions: voice communication only, CCMs only, voice + CCMs, and control (no communication enabled).

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Extensive research has been conducted in the area of verbal communication in groupware [14, 17], group work [19], and gameplay [4, 13, 26, 32]. However, CCMs are a novel feature of cooperative multiplayer games and their effectiveness is yet to be explored completely. The increasing inclusion of CCMs in these games by their designers leads us to pose our primary hypothesis: **We expect team performance will be best when given access to communication mechanics**, particularly the combination of voice and CCM.

2 BACKGROUND

Multiplayer games can be either competitive or cooperative. In competitive games, players work against each other, while in cooperative games, players create strategies together as a dyad or a team [42]. Recently, multi-player games have leaned towards providing cooperative-play modes [24], while also including several custom in-game mechanics that could be useful towards communicating with one's partner.

In this section, we offer a brief primer on team performance and communication, describe game design and mechanics, cover the features of collaborative virtual environments (games), and describe the CCM framework [33].

2.1 Team Performance and Coordination

The present research is grounded in the team performance and cognition literature. Teams are a "[...]distinguishable set of two or more people who interact, dynamically, interdependently, and adaptively toward a common and valued goal/objective/mission, who have been assigned specific roles or functions to perform, and who have a limited life-span of membership[...]" [29]. A team's ability to think and act collectively is called *team cognition* [11, 25].

2.1.1 Team Cognition

In team cognition theory, teams are considered as a unit capable of thought [11, 25]. Team members communicate to enable progress, coordinating action. Information sharing does not automatically translate to improved clarity, and communication, especially unnecessary communication, leads to a rise in communication overhead [9, 25]. *Communication overhead* is the cost of communicating, both to the sender and recipient, in terms of attention, cognition, time, and bandwidth. Consequently, efficient teams decrease communication overhead when they *implicitly coordinate* [9, 10, 34] by anticipating partners' information needs.

Smart decisions about communication modality (e.g., voice, gesture, CCMs) can reduce communication overhead. Communication is thus a component of gameplay, as decisions about what to communicate and when have an impact on game state (sometimes indirectly, through other players) and have a cost associated with them. The present study focuses on the effectiveness of the CCMs in a gameplay, identifying impact on communication overhead.

2.1.2 Situation Awareness

Situation awareness incorporates the perception of relevant situation and environmental elements, the comprehension of the meaning of these elements, and how such elements could change [7, 8].

A player who exhibits a high-level of situation awareness, while playing cooperative games, typically makes intelligent decisions regarding his/her next action in a scenario, thus effectively supporting his/her team in task completion and potentially reducing communication overhead [32]. In games, players might not always be able to convey a message through their actions, this is when their partner may need to make an informed guess about what the actions imply. Cheung et al. [4] indicate that players who share a location in the game environment exhibit implicit coordination: they speak less and act more [9], which they use to collaborate in addition to the existing communication channels. One significant communication channel used by players in a shared environment is virtual gestures using an avatar [22].

2.2 Game Mechanics

Game design deals with the construction of rules and play-enabling structures [31]. *Rules* are constraints on action, while the ability and degrees of freedom afforded within a set of rules is defined as *play* [31]. *Game mechanics* represent moments of player choice that advance the game state [21, 31] and a game's *core mechanics* are those mechanics that players repeat. As players make choices, they exchange one outcome for another, cutting off other choices. Thus, the decision to communicate, through voice or CCMs, may be done at the cost of engaging other game mechanics (e.g., firing a portal gun in time) or generating communication overhead.

2.3 Collaborative Virtual Environments and Games

Collaborative virtual environments are shared computer simulated spaces in which users interact [1, 16, 43]. Such environments may be fully 3D, 2D, or even text-based (e.g., Multi-User Dungeons [6]). Collaborative virtual environments, of which cooperative digital games are a subset, support communication and shared activity. The virtual environments of games, which function as human-computer interfaces, are known as "*gameworlds*" [20], a term that we use throughout the paper. Prior research has identified a need for communication and gesture-based interaction in collaborative virtual environments [3, 40, 43]. While communication has been studied directly [4, 13, 26, 32], the importance of gesture-based interaction (e.g., CCMs) have not been deeply studied.

2.3.1 Deictic Communication

Deixis, in which context is used in conjunction with language to clarify meaning makes communication more efficient since complex locations and object descriptions can be replaced in speech by a simple gesture [35]. CCMs enable deictic communication in games. When people negotiate shared meaning in natural, face-to-face settings they rely on multiple modes of communication [39, 41], yet collaborative virtual environments are often impoverished in this regard. Prior research in the field of deictic communications indicated that speech is less useful for describing locations and objects which are accessible to the user with other tools such as pointers and gestures [5]. Shared spaces in which users can visually indicate what action to take, are key to maintaining situation awareness and successfully working together [14, 15]. Wong and Gutwin have explored the design of pointers in collaborative virtual environments [40, 41]; we note that *Portal 2*'s CCM pointers follow Wong and Gutwin's design implications for effective deixis.

2.3.2 Embodied Communication

According to Galantucci and Steels, embodied communication entails that the individuals who are involved in a communication have a body with which they are present in the world; they can only communicate through this body when they cannot communicate through any other direct method to transfer meaning [12]. Avatars, capable of communicating through CCMs, offer players a means to communicate in an embodied way.

2.4 Cooperative Communication Mechanics

Many cooperative games offer the opportunity to use game mechanics to share information and coordinate action without using voice or text chat; these are *cooperative communication mechanics* [33]. Because they are game mechanics, players actively make decisions about when and how to engage CCMs to advance game state, at the cost of invoking other mechanics. We previously provided a classification framework for CCMs based on the activities they afford players [33]. Of these types, the most salient CCMs to the present research are ATTENTION-FOCUSING, EXPRESSIVE, EMERGENT.

ATTENTION-FOCUSING game mechanics enable the players to provide directives to each other during the game play. Without embodied communication, giving deictic references becomes difficult, this is where ATTENTION-FOCUSING CCMs help in enabling deictic communication. ATTENTION-FOCUSING mechanics are subdivided into two more types: UNBOUND and SEMANTICALLY IMBUED. UNBOUND refers to those mechanics which do not provide any additional information, whereas SEMANTICALLY IMBUED are those which provide some shared meaning, encoded in the game's rules and interface.

EXPRESSIVE mechanics support players in sharing information about themselves. They are used to plan and to share emotions.

EMERGENT mechanics have not been designed for communication, but have been appropriated by players as a meaningful way of communication. These mechanics do *not* have a communicative meaning, might have to be learned during gameplay, and may be meaningful only within certain communities.

3 GAME STUDY CONTEXT: *Portal 2*

Portal 2 [37] is an exceptionally popular[1] first-person puzzle-platform shooter digital game that includes an in-depth cooperative-play mode.

In the cooperative-play mode of *Portal 2*, a dyad of players works together to solve puzzles in a first-person perspective using the *portal gun* core mechanic. The portal gun allows a player to create two linked *portals*, openings on surfaces of the gameworld through which avatars and objects can instantly pass. Players must shoot at least twice, using each of two portal-firing controls, to specify the two portal locations. Once two portals are placed, objects can pass between them.

Players must avoid hazards and manipulate a number of puzzle elements (e.g., moving blocks through portals to land on pressure plates, avoiding turrets and pits, activating buttons in isolated rooms in the correct order), to find and reach the exit of each *test chamber*. *Portal 2* features several *cooperative scenarios*, points in a test chamber at which players need to work together to progress. Players coordinate their actions using CCMs and traditional voice. *Portal 2* was chosen for this study due to its extensive set of CCMs that follow prior guidelines for effective deictic communication (e.g., [40, 41]).

3.1 Ping Tools

Ping tools are ATTENTION-FOCUSING CCMs that enable players to indicate a location in the gameworld. There are two ping tools, the *look ping* (Figure 1) and the *timer ping* (Figure 2); these designs support Wong and Gutwin's design implications for successfully pointing in collaborative virtual environments [40, 41].

The look ping (Figure 1), an UNBOUND ATTENTION-FOCUSING CCM, is used to direct the focus of one's partner, serving to grab attention, provide instruction for portal placement, identify where

[1] As of December 9, 2015, Metacritic reports *Portal 2* as having a 95/100 Metascore from 52 critics and an 8.8/10 user score from 5,611 ratings (`http://www.metacritic.com/game/pc/portal-2`). Steam reports 98% positive reviews from 58,554 reviews (`http://store.steampowered.com/app/620/`).

Figure 1: UNBOUND ATTENTION-FOCUSING CCM *look ping* in action; with the blue players's view at left and the orange player's at right. On left, blue fires a look ping outside the view of orange, who can see the blue ping indicator on the edge of her/his head-up display.

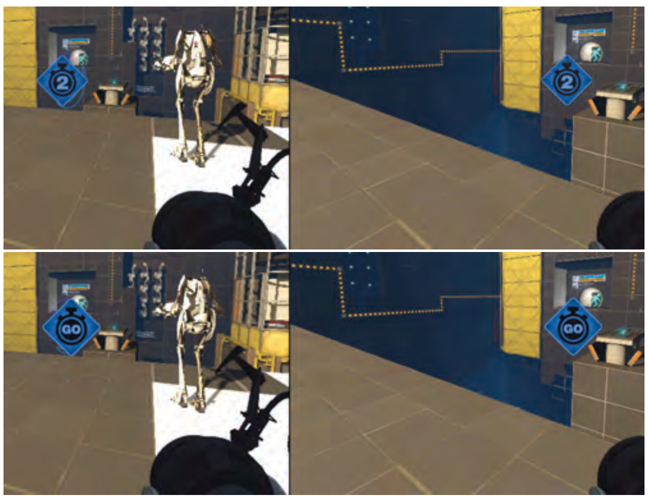

Figure 2: SEMANTICALLY IMBUED ATTENTION-FOCUSING CCM timer ping in action. Each figure shows a split-screen view: the blue player's view is left and orange is right. On top, the countdown timer is at 2; on bottom, it now reads “GO”. This indicates that players should synchronize activity at a gameworld location.

an avatar should stand, or other purposes. Because it is UNBOUND, it carries no information other than to direct the other player's attention; further disambiguation requires other means of communication or an established meaning. Thus, we expect that voice communication is key to making effective use of the look ping.

Wong and Gutwin recommend that deictic pointing gestures be held long enough to establish mutual understanding [40]. The look ping implements these design implications: it persists for several seconds in the gameworld and players' head-up displays after being fired. Further, *Portal 2* pings are similar what Wong and Gutwin call a “spotlight pointer”, which was one of the more effective forms of pointing studied in their research [41], although the spotlight pointer studied was small and difficult for users to perceive. If the ping is off-screen, an indicator appears at the edge of a player's head-up display to inform her/him of its relative location.

The timer ping (Figure 2), a SEMANTICALLY IMBUED ATTENTION-FOCUSING CCM, enables players to synchronize action. Many puzzles require this level of precision to complete cooperative scenarios (e.g., simultaneously pressing a pair of buttons to open a door). The timer ping functions similarly to the look ping, except that the indicator is *imbued with semantics*: a three-second countdown shown on the indicator that concludes with “GO”. The exact nature of the action taken at the end of the countdown must

Figure 3: A split-screen view of the high-five gesture, one of the many available EXPRESSIVE gestures in *Portal 2*.

be otherwise coordinated by the players, although it is frequently obvious when directed at specific game elements that afford synchronized action.

3.2 Gestures

In cooperative play mode, *Portal 2* includes several EXPRESSIVE CCMs [33]: individual and cooperative gestures, (e.g., facepalm, thumbs-up, dance moves, or a cooperative high five, as in Figure 3). These can be used to grab a player's attention, convey information about the outcome of an event, or express emotion.

4 METHODS

This study was completed with permission from the New Mexico State University Institutional Review Board (protocol #12356: Analyzing Cooperative Communication Mechanisms of *Portal 2*).

4.1 Pilot Study for Test Chamber Selection

We use custom test chambers because we expect a large number of potential participants will already have familiarity with the official *Portal 2* cooperative-play test chambers. Prior to the present experiment, a validation study was performed to ensure the custom-designed test chambers chosen match the requirements of the study: a moderate level of difficulty and featuring cooperative scenarios where players are forced to work together to progress, requiring communication. For this purpose, we developed nine custom test chambers and selected four for the study (details of this process can be found in our prior work [36]); Figure 4 shows the test chamber preview images. For the study, player pairs from three different levels of expertise: beginner, intermediate and expert were recruited and made to play the custom test chambers. The results showed that the experts found the selected test chambers to be easy, the intermediates reported the test chambers to be medium level of difficulty and beginners indicated them to very difficult. Observations from this study also showed that the test chambers include cooperative scenarios and require a significant amount of communication between players.

4.2 Recruitment

Participants from the university and local community members were invited to participate in the formal experiment. As we considered relationship period a co-variate in the study, we required that participants register in pairs.

4.3 Hypotheses and Statistical Design

For the current study, we utilized a within-subjects design with a single independent variable (IV): communication condition, with four levels representing the means of communication available to the players: voice only, CCM only, voice + CCM, and control (no communication mechanics used). The dependent variables (DVs) were completion time of various milestones in the test chambers. As previously mentioned, our **primary hypothesis was that using voice and CCM communication game mechanics would lead to**

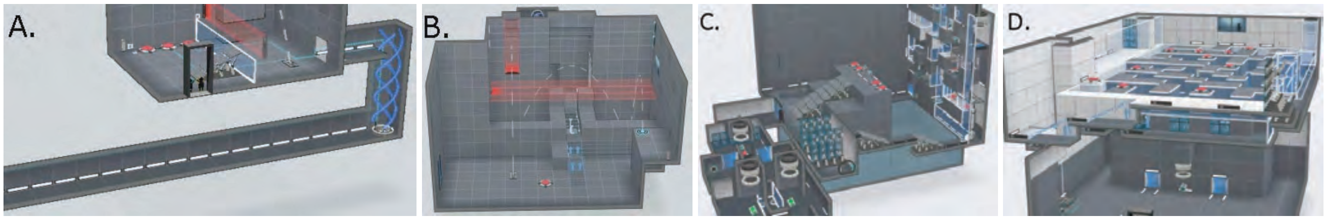

Figure 4: The custom-designed and validated test chambers for the study developed in our prior work [36].

quicker completion times of *Portal 2* test chambers than without those tools. We expected that teams would perform best in the voice + CCM condition, then voice only, then CCM only, and finally control. Additionally, since pairs of participants were recruited who already knew each other and prior literature (e.g., [27]) shows beneficial collaborative effects among partners when they have an established relationship, our **secondary hypothesis was that the length of time that the participants knew each other would be negatively correlated with completion times of the test chambers**. Thus, length of relationship between the players was recorded and used as a covariate in the analyses.

4.4 Randomized Conditions

A fully crossed study would have required at least 576 runs (4! possible test chamber orders $\times$ 4! possible communication condition orders) with 1,152 unique participants. Because this number of study runs was beyond the scope of the present work, we instead opted to randomize the order of communication conditions and the test chambers played by the participants [23] .

In each study session, the dyads played four games for data collection, during which they experienced all four test chambers (A, B, C, D; shown in Figure 4) in a random order, each randomly combined with one of the communication conditions (voice only, CCM only, voice + CCM, control). The order of communication conditions and the test chambers played by the participants was randomized to counter-act learning and order effects. The participants were allowed to take breaks in between the four games to decrease fatigue [23].

4.5 Study Protocol

After being shown into the lab, participants provided informed consent. The participants were then asked to complete a demographics questionnaire, a relationship-assessment questionnaire, followed by an initial NASA Task-Load Index (TLX) assessment [18][2]. The demographics questionnaire covered age, gender, education, general questions that help the experimenter understand the *Portal 2* expertise and gaming expertise that were based on the game technology familiarity questionnaire [28]. After playing each test chamber, the TLX was re-administered along with questions aimed at assessing communication performance.

Before playing, we aimed to ensure that participants were familiar with *Portal 2* and its cooperative-play mode. Each team was shown a *Portal 2* cooperative-play walkthrough video[3], which involves most of the game mechanics used in the custom-designed test chambers. Participants were made to play a tutorial test chamber, also custom designed, keeping in mind the game mechanics that they would encounter in the actual test chambers. The tutorial included a written step-by-step walkthrough, which directed the players on how to complete the test chamber. In this test chamber, both voice and CCMs were enabled and the participants were also allowed to ask the experimenter for assistance. Any questions about the game, the game mechanics, the controller buttons, and the CCMs were answered while playing this test chamber to make sure participants were as well-equipped as possible to play the game.

After completing these two preparation steps, the participants played the four custom-designed test chambers (Figure 4) for which they were provided a maximum of 30 minutes per test chamber. To enforce the four communication conditions, the controller button settings were changed to enable or disable CCMs accordingly before every test chamber. To make sure there is no voice communication in the CCM-only and control conditions, the microphones of the participants were disabled.

We concluded each study session with an interview of the dyads.

[2] We note that we administered the TLX here for transparency about the study design, but the TLX data is for a different study.

[3] *Portal 2*: Co-op Walkthrough - Part 1 by Valve Corporation, `https://www.youtube.com/watch?v=JX7R6wvPg8o`.

4.6 Apparatus

Participants played *Portal 2* in a laboratory with separated rooms. Separation allowed two advantages: it increased ecological validity and afforded more control over the communication conditions. Both the rooms were equipped with identical computers: Intel Core 2 (Quad Core) 2.34 GHz processor, 8GB RAM, 1TB hard drive, and an NVIDIA GeForce 9300 GE video card along with a 1080p HD 24 inch widescreen monitor. The computers ran 64-bit Windows 7 Professional Version. Each machine featured a microphone / headphone combination to enable voice communication and a Microsoft wired Xbox 360 controller to control the game.

4.7 Data Collection

During the user study, the gameplay video and audio (both in-game and microphone input) were recorded using Fraps 3.5 [2], a Windows application long-used to record gameplay with minimal impact on performance. In addition to the audio and video recording, we collected questionnaire responses and TLX data.

5 Experiment Execution

Data collection occurred over a four weeks period in the fall of 2015. The study length was approximately two hours for each dyad.

A total of 20 dyads ($N = 20$) were recruited for the study. Eight participants were female and 32 were male. The average age of the participants was 24 years ($SD = 3.1$, $N = 40$). Regarding educational background: over 50% of the participants are presently pursuing or completed a bachelor's or a Master's degree.

We recorded length of relationship (in months) to use as a covariate in the analyses, statistically controlling for noise from this factor. Seventeen pairs indicated that their relationship was "friends"; two pairs who were "in a relationship" and there was one a pair of "brothers." The relationship period of the dyads ranged from one month to nineteen years.

We considered expertise level as a potential covariate, but there was insufficient variability in this factor for it to impact the results. Using participants' survey responses about their experience playing *Portal 2*, we identified participants as beginners, intermediates, or experts. *Beginners* have never played *Portal 2*; *intermediates* have played some *Portal 2*, but not all of the game; and *experts* have played the entire game. With the exception of two dyads, the teammates had equal levels of expertise: there were four expert teams, one intermediate team, 13 beginner teams, one team with a beginner and an expert, and one team with a beginner and an intermediate.

6 Analysis Methods

6.1 Milestone-Based Game-Progress Coding Scheme

The custom-designed test chambers used in the study were chosen to ensure that there are a number of cooperative scenarios. Initially we planned to analyze the data only based on the time taken for completion of each entire test chamber by the teams. However, a significant number of teams did not reach the end of the test chambers within the maximum allowed time.

We developed a milestone-based game-progress coding scheme. The *milestones* (MS) were developed by independently playing the levels and assessing the number of puzzle-solving steps that the research team required to complete the test chamber. We then analyzed the minimum number of mandatory steps that we needed to successfully complete each test chamber. We discussed our sequence of steps and mutually agreed on MS after comparing our individual analyses. The milestones (MS1, MS2, MS3) were then formed by distributing these steps evenly, considering the complexity and time taken to complete each of them throughout the test chamber. This offered the ability to break down player progress through the test chambers, providing a fine-grained means of assessing performance.

The research team used the scheme to code the video data. This allowed us to assess the average of the time taken by the participants to cross each milestone. The milestones with detailed communication requirement for each test chamber from A to D can be seen in Appendix B (Supplementary Material).

6.2 Statistical Analyses

We used analyses of covariance (ANCOVA) to investigate the differences among CCMs.

7 Results

In the present paper, we only consider the first (MS1) and second (MS2) milestones of all of the test-chambers; data on the the third milestone is omitted because an overwhelming majority of teams did not reach this milestone regardless of which communication condition they were in, precluding us from including it in the analyses. MS1 was attained in all of the chambers by all players; MS2 was attained 84 percent of the time, across dyads and conditions.

7.1 Game Progress

Completion times for the milestones were calculated by observing the recorded video. Descriptive statistics of the communication conditions for the first and second milestones are in Table 3; values are in seconds. We initially conducted an ANCOVA with CCM condition as the IV, time taken to complete MS1 the DV, and length of relationship as a covariate. The analysis revealed that communication condition has a significant impact on time taken for completion of MS1 [$F(3,54) = 7.06$, $\eta^2_p. = .28$, $p < .001$], and that length of relationship was not significant [$F(1,18) = 4.11$, $\eta^2_p. = .19$, $p = .058$]. Sidak-adjusted pairwise comparisons showed that players reached MS1 quicker in the voice only and voice + CCM conditions than in the control condition ($ps < .005$), with no other significant differences; thus hypothesis 1 was partially supported. Follow-up correlations showed a non-significant negative relationship between completion of MS1 and the length of the relationship between the players, [$r(19) = -.43, p = .058$)]. The relationship itself could support hypothesis 2.

Due to the inability of some dyads to attain MS2 in some conditions and our experiment's repeated-measures design, the usable

Table 1: Description of variables. Note that experience was considered as a covariate and rejected due to lack of variance.

variable	description
communication condition (IV)	voice only; CCM only; voice + CCMs; control (no communication ability)
MS1 time (DV)	Time taken to complete the first milestone in seconds.
MS2 time (DV)	Time taken to complete the second milestone in seconds.
number of CCMs used (DV)	Number of times a player indicated a ping or used a portal shot (EMERGENT CCM)
covariate	Period of relationship between partners in months.

dataset was reduced to 10 dyads. In contrast to the pattern observed in the analyses of MS1 completion times, the second ANCOVA revealed that communication condition did not significantly impact the time taken to complete MS2 [$F(3,24) = 1.29$, $\eta^2_p. = .14$, $p = .3$], and that length of relationship did not covary significantly with time to complete MS2 [$F(1,8) = 1.45$, $\eta^2_p. = .15$, $p = .26$]. In all, both hypotheses were supported for completion times of MS1, and neither were supported for completion times of MS2.

Because there is a significant difference in completion times based on communication conditions for the first milestone but not the second, we unpack the descriptive statistics for completion times for MS1 and MS2 on Table 3. Players' time to complete MS1 is most affected in the voice + CCM condition, followed by voice only and CCM only. This pattern was not in evidence for completion times of MS2, illustrating the particular CCMs the dyads were using, CCMs only affected the initial part of the gameplay.

7.2 CCM Observations

As a secondary source of data, and to understand player behavior in cooperative play, we investigate the number of pings and portal shots employed by players, as well as the use of gesture EXPRESSIVE CCMs. As above, we analyze the resulting video to count the number of times players used pings (both types), the number of portal shots taken, and the number of EXPRESSIVE gestures. The pings are a form of ATTENTION-FOCUSING CCM, while we take portal shots to be an EMERGENT CCM that is also used to focus attention.

While some portal shots were used only to focus attention, most enabled progress through the game. This is a limitation of the present data, since there is no meaningful way to tease these apart in analysis. Since portal shots were available in all conditions (while pings were not always allowed), we are able to track their usage.

The average number of pings and portal shots, as well as the sum of both, for each condition, is described on Table 2. This observation shows that when the players are not given access to voice communication they make excessive use of CCMs and when both voice and CCMs are unavailable they use portal shots as indicators and means of communication. When voice communication is not available, the average of the number of portal gun shots (167.2) and portal gun shots + CCMs (178.5) is similar. As expected, it appears that players use the portal shot as an EMERGENT CCM when other CCMs are unavailable; we also observed that, when CCMs are available, players make ready use of them.

Although this study does not aim to deeply analyze avatar gestures, we noted that, if the players were given access to them, only 15% of the teams used them and only to celebrate their success at the end of a test chamber. The data do not indicate that participants use EXPRESSIVE gestures to advance gameplay.

Table 2: Mean total uses of the ping CCM and portal shots (considered as an EMERGENT CCM) by communication condition.

communication condition	# pings		# portal shots		combined	
	mean	SD	mean	SD	mean	SD
voice only	N/A		30.6	35.8	30.6	35.8
CCM only	105.7	68.2	61.6	57.4	167.2	98.7
voice + CCM	38.0	65.7	33.7	24.3	71.6	67.3
control	N/A		178.5	110.3	178.5	110.3

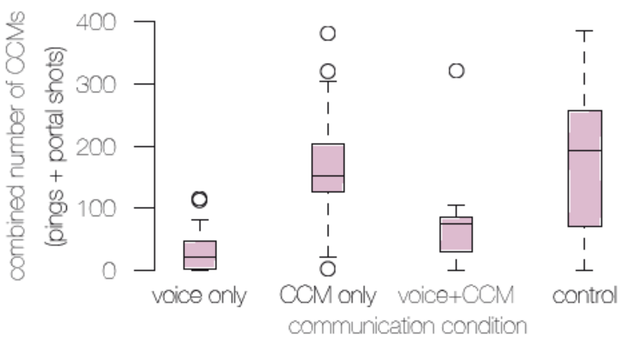

Figure 5: Mean combined uses of the ping CCM and portal shots by communication condition. Same data on Table 2.

7.3 Interview Results

The interview questions were designed to get a direct feedback from the participants about their experience with the game. We supply these, as secondary evidence to the primary statistical findings, to unpack players' experience using CCMs to cooperate in play. Prior data reports on dyads, but the interviews include responses from both team members ($N = 40$).

When asked which communication mode was most effective, all forty participants reported that voice was the most effective. Most participants explained that voice is easier, faster, more natural, and can be undertaken while performing other tasks. Moreover, more than half of the respondents mentioned that CCMs in combination with voice helps communicating in some scenarios because one can explain and show what the partner needs to do. Six respondents reported that CCMs were not easy to understand and provided limited options. To unpack the role of relationships in play, we asked participants if knowing their partner helped them in communicating better; only fifteen participants answered that it helped, while others believed that knowing the game is more important than knowing the partner to communicate better in the game.

8 Discussion

Our hypotheses were partially supported. Team performance was mediated by use of CCMs and voice in the initial stages of a game, but seemed to matter less as the game progresses. We also found that extensive communication in-game was achieved through use of the core mechanic—portal shots. Similar to the primary finding, the data indicate that impact of relationship was only a contributing factor in the early stages of gameplay. We discuss the significance of these findings in the following section.

8.1 Team Performance Hypothesis

The ANCOVA results showed there is a significant effect of communication condition on completion times of MS1 but not MS2. The descriptive statistics unpack the differences between CCMs for MS1, indicating that the best performance in completing MS1 occurred with voice + CCMs, followed by voice only, then CCM

Table 3: Descriptive statistics of finish time for milestones 1 and 2 by communication condition. All times are in seconds (s). Teams that failed to complete MS2 in a test chamber were excluded.

	communication condition	seconds to complete MS mean	SD	N
MS1	voice only	379.0	362.3	20
	CCM only	530.4	481.3	20
	voice + CCM	281.9	211.9	20
	control	675.8	500.0	20
MS2	voice only	497.9	333.3	16
	CCM only	488.8	301.4	14
	voice + CCM	654.4	363.6	18
	control	456.6	378.3	15

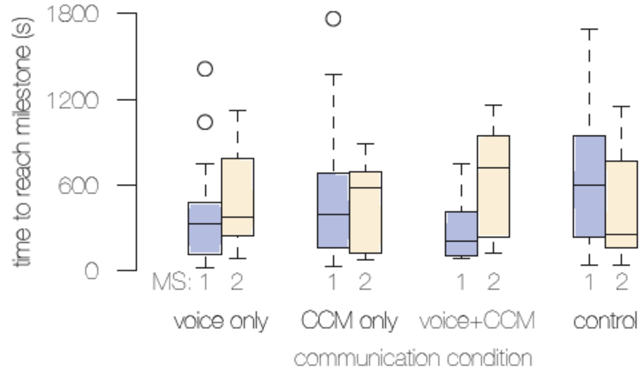

Figure 6: Mean time taken (in seconds) for each milestone, organized by communication condition. Teams that failed to complete MS2 in a test chamber were excluded. Same data on Table 3.

solely; only voice and voice + CCM conditions were significantly faster than control. Potentially, as player dyads gained competency, the specific CCM mattered less than the actual deployments of CCMs. Perhaps this effect of communication mechanics is valid only until the players become comfortable with the game and its mechanics, as well as the needed team coordination dynamics. Once they have reached some mastery of the game they make effective use of implicit coordination to reduce communication overhead.

The analysis of the interview data shows that all players prefer voice communication and feel a need for CCMs in some scenarios where they need to point out things in the game environment which supports the team performance hypothesis. Participants mentioned that CCMs usage is not straightforward and needs learning and experience, they do not always convey what the partner wants and understanding them takes time which makes their usage harder.

It appears that CCMs do enable players to supplant some voice communication in play. We observe that, according to Table 2, players use substantially fewer CCMs when they have access to voice (voice only and voice + CCMs conditions). In the voice + CCM condition, we expect voice to be needed to disambiguate the purpose of CCM usage. At the same time, when voice is unavailable, players extensively use CCMs to communicate. Taken together, as expected, these results suggest that each type of communication has its own value and that CCMs are critical to successful play in cooperative games, likely due to their importance in deixis.

8.2 Impact of Relationship

As predicted, length of relationship between the players did positively influence their performance, but only for the completion times of MS1. This is akin to the pattern noted with the primary hypothesis, and a similar explanation fits the current pattern. As players became comfortable with each other after completing MS1 and gained some level of team coordination mastery, their prior relationship mattered much less for completing MS2. In addition, based on interview data, participants report that knowing their partner helped in communicating better. Participants responded that it to know their partner because they could anticipate what their partner will understand from a specific gesture and act according to it, which suggests the occurrence of implicit coordination and effective situation awareness. At the same time, some reported that it does not help knowing the partner unless the partner knows the game, suggesting that situation awareness as it applies to the game is an important aspect of team mastery of the game. Unfortunately, our sample was not varied sufficiently on expertise to determine whether or not this is true. Further research is needed to unpack the effects of relationship and expertise on gameplay.

8.3 EMERGENT CCMs

An interesting observation is the use of portal shots. We categorize these as an EMERGENT CCM: portal shots are not a game mechanic provided for communication, but players used it as a form of CCM because they are highly visible, easily targeted, and readily available. In the absence of other communication mechanisms, participants used portal shots to grab a partner's attention (ATTENTION-FOCUSING), indicate a location or object (ATTENTION-FOCUSING), or to indicate emotions (EXPRESSIVE). The average number of portal shots are in synchronization with the use of the CCM when available (e.g., 167.2 and 178.5, see Table 2), this observation indicates that when the CCMs are non-existent the players miss their presence and creatively come up with new methods to compensate for them, which also points out the overall importance of CCMs in cooperative gameplay.

9 CONCLUSION

In this study, we analyzed the effectiveness of cooperative communication mechanics (CCMs) in *Portal 2*. The cooperative-play mode of *Portal 2* presents puzzles to the players that forces them to communicate with the partner, where they make decisions and work together to reach a common goal as a team.

The statistical analysis of gameplay data along with the interview data of the study shows that players performed the best when they were given access to voice and CCM, and when they had an established relationship with the other player, but only during the initial stages of gameplay. Thus, the hypotheses were only partially supported. However, the lack of differences in completion times of the second milestone because of various communication mechanics and prior relationships is, in itself, an important finding when contrasted with performance in completing the first milestone. It suggests that, as gameplay proceeds, existing differences in game mechanics and player's background fall away, supporting a parallel experience for all players.

An interesting observation from the study is the use of portal shots as an EMERGENT CCM, which we expected based on our prior work in framing CCMs [33]. Players used portal shots to compensate the non-existence of any other communication mode while playing the game. They used it to indicate location, objects, and express their emotions. Generally, CCMs are likely more useful when game mechanics cannot be explicitly turned in CCMs or when the gameplay features CCMs prominently and explicitly.

9.1 Limitations of the Study

Although the study was carefully developed and controlled, it has some limitations. The first is that we have few data on the long-term effects and/or value of the use of CCMs on team performance. Study participants may have experienced a novelty effect from using them. Since most of our dyads (13/20) were *Portal 2* beginners, they had not experienced using the ping tools before. We suggest that valuable future work in this space could investigate the long-term value of CCMs, such as observations of only expert players or eSports players.

A further limitation is the inability to fully cross CCMs and test chambers; necessitating the use of a quasi-random design. The necessary iterations to run an exhaustive study was beyond the scope of this work (requiring over 1,000 test subjects, at a minimum). Further iterations of the study could strengthen our understanding of the use of CCMs in gameplay.

9.2 Future Work

Future research will test and analyze CCMs in a game that lacks a game mechanic that can obviously be used as an EMERGENT, ATTENTION-FOCUSING CCM. At the same time, we expect that players will *find a way* to communicate with one another through game mechanics, as is the nature of EMERGENT CCMs. Future research on how players use the avatar gestures to communicate in the absence of other communication conditions could help the game designers to develop much more valuable and functional avatar gestures. Exploring these will give a deeper insight of the effectiveness of CCMs in cooperative games.

9.3 Closing

The present research has identified the combination of CCMs and voice as being essential to team performance in cooperative video games. The data further indicate that, individually, CCMs and voice also support performance. We observe that players develop EMERGENT CCMs as-needed to support coordination. Thus, we recommend that designers of cooperative-play digital games supply both voice and CCMs as much as possible.

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REFERENCES

[1] R. A. Bartle. *Designing Virtual Worlds*. New Riders, 1st edition, 2003.

[2] Beepa. *Fraps*. Software [Windows], 2013.

[3] B. Brown and M. Bell. CSCW at play: 'There' as a collaborative virtual environment. In *Proceedings of the 2004 ACM Conference on Computer Supported Cooperative Work*, CSCW '04, pages 350–359, New York, NY, USA, 2004. ACM.

[4] V. Cheung, Y.-L. B. Chang, and S. D. Scott. Communication channels and awareness cues in collocated collaborative time-critical gaming. In *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work*, CSCW '12, pages 569–578, New York, NY, USA, 2012. ACM.

[5] P. Cohen. Speech can't do everything: A case for multimodal systems. *Speech technology magazine*, 5(4), 2000.

[6] P. Curtis. Mudding: Social phenomena in text-based virtual realities. *High Noon on the Electronic Frontier: Conceptual Issues in Cyberspace*, pages 347–374, 1992.

[7] M. R. Endsley. Toward a theory of situation awareness in dynamic systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 37(1):32–64, 1995.

[8] M. R. Endsley. Theoretical underpinnings of situation awareness: A critical review. In M. R. Endsley and D. J. Garland, editors, *Situation Awareness Analysis and Measurement*, pages 3–6. Lawrence Erlbaum Associates, Mahwah, NJ, USA, 2000.

[9] E. E. Entin and D. Serfaty. Adaptive team coordination. *Human Factors*, 41(2):312–325, June 1999.

[10] J. A. Espinosa, F. J. Lerch, and R. E. Kraut. Explicit versus implicit coordination mechanisms and task dependencies: One size does not fit all. In Salas and Fiore [30], pages 107–130.

[11] S. M. Fiore, H. M. Cuevas, J. W. Schooler, and E. Salas. Cognition, teams, and team cognition: Memory actions and memory failures in distributed team environments. In C. A. Bowers, E. Salas, and F. Jentsch, editors, *Creating High-Tech Teams*, number 4, pages 71–87. American Psychological Association, Washington, DC, USA, 2006.

[12] B. Galantucci and L. Steels. The emergence of embodied communication in artificial agents and humans. In I. Wachsmuth, M. Lenzen, and G. Knoblich, editors, *Embodied Communication in Humans and Machines*, pages 229–256. Oxford University Press, Oxford, England, 2008.

[13] D. Geerts. Comparing voice chat and text chat in a communication tool for interactive television. In *Proceedings of the 4th Nordic Conference on Human-computer Interaction: Changing Roles*, NordiCHI '06, pages 461–464, New York, NY, USA, 2006. ACM.

[14] D. Gergle, R. E. Kraut, and S. R. Fussell. Language efficiency and visual technology: Minimizing collaborative effort with visual information. *Journal of Language and Social Psychology*, 23(4):491–517, December 2004.

[15] D. Gergle, R. E. Kraut, and S. R. Fussell. Using visual information for grounding and awareness in collaborative tasks. *Human–Computer Interaction*, 28(1):1–39, 2013.

[16] C. Greenhalgh and S. Benford. Massive: A collaborative virtual environment for teleconferencing. *ACM Trans. Comput.-Hum. Interact.*, 2(3):239–261, Sept. 1995.

[17] C. Gutwin and S. Greenberg. A descriptive framework of workspace awareness for real-time groupware. *Comput. Supported Coop. Work*, 11(3):411–446, Nov. 2002.

[18] S. G. Hart and L. E. Staveland. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research: Results of empirical and theoretical research. In P. A. Hancock and N. Meshkati, editors, *Human Mental Workload*, volume 52 of *Advances in Psychology*, pages 139 – 183. North-Holland, 1988.

[19] C. Heath and P. Luff. Collaboration and control: Crisis management and multimedia technology in London Underground line control rooms. *Comput. Supported Coop. Work*, 1(1):69–94, 1992.

[20] K. Jørgensen. *Gameworld Interfaces*. MIT Press, Cambridge, MA, USA, 2013.

[21] J. Juul. *Half Real: Video Games between Real Rules and Fictional Worlds*. MIT Press, Cambridge, MA, USA, 2005.

[22] T. Kujanpää and T. Manninen. Supporting visual elements of non-verbal communication in computer game avatars. In *DiGRA #3903 - Proceedings of the 2003 DiGRA International Conference: Level Up*, volume 2, pages 220–231, 2003.

[23] J. Lazar, J. H. Feng, and H. Hochheiser. *Research Methods in Human-Computer Interaction*. Wiley Publishing, 2010.

[24] M. Loomis. The rise of online multiplayer games and the collapse of couch co-op. Website, January 2015. `http://gamerant.com/rise-of-online-multiplayer-games-couch-coop/`.

[25] J. MacMillan, E. E. Entin, and D. Serfaty. Communication overhead: The hidden cost of team cognition. In Salas and Fiore [30], pages 61–82.

[26] P. J. McClelland, S. J. Whitmell, and S. D. Scott. Investigating communication and social practices in real-time strategy games: Are in-game tools sufficient to support the overall gaming experience? In *Proceedings of Graphics Interface 2011*, GI '11, pages 215–222, School of Computer Science, University of Waterloo, Waterloo, Ontario, Canada, 2011. Canadian Human-Computer Communications Society.

[27] D. McDaniel and R. R. McDaniel. A field of study of the effect of interpersonal trust on virtual collaborative relationship performance. *MIS Q.*, 28(2):183–227, June 2004.

[28] M. W. McEwan, A. L. Blackler, D. M. Johnson, and P. A. Wyeth. Natural mapping and intuitive interaction in videogames. In *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-human Interaction in Play*, CHI PLAY '14, pages 191–200, New York, NY, USA, 2014. ACM.

[29] E. Salas, T. L. Dickinson, S. A. Converse, and S. I. Tannenbaum. Toward an understanding of team performance and training. In R. W. Swezey and E. Salas, editors, *Teams: Their Training and Performance*, pages 3–29. Ablex Publishing Corporation, Norwood, NJ, USA, 1992.

[30] E. Salas and S. M. Fiore, editors. *Team Cognition: Understanding the Factors that Drive Process and Performance*. American Psychological Association, Washington, DC, USA, 1st edition, 2004.

[31] K. Salen and E. Zimmerman. *Rules of Play: Game Design Fundamentals*. The MIT Press, 2003.

[32] A. Tang, J. Massey, N. Wong, D. Reilly, and W. K. Edwards. Verbal coordination in first person shooter games. In *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work*, CSCW '12, pages 579–582, New York, NY, USA, 2012. ACM.

[33] P. O. Toups Dugas, J. Hammer, W. A. Hamilton, A. Jarrah, W. Graves, and O. Garretson. A framework for cooperative communication game mechanics from grounded theory. In *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-human Interaction in Play*, CHI PLAY '14, pages 257–266, New York, NY, USA, 2014. ACM.

[34] P. O. Toups Dugas and A. Kerne. Implicit coordination in firefighting prac-tice: Design implications for teaching fire emergency responders. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '07, pages 707–716, New York, NY, USA, 2007. ACM.

[35] E. Tse, S. Greenberg, C. Shen, and C. Forlines. Multimodal multiplayer tabletop gaming. *Comput. Entertain.*, 5(2), Apr. 2007.

[36] D. Vaddi, R. R. Wehbe, P. O. Toups Dugas, S. N. Stahlke, R. Koroluk, and L. E. Nacke. Validating test chambers to study cooperative commu-nication mechanics in Portal 2. In *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play*, CHI PLAY '15, pages 721–726, New York, NY, USA, 2015. ACM.

[37] Valve Corporation. *Portal 2*. Game [Windows], 2011.

[38] G. Wadley, M. Carter, and M. Gibbs. Voice in virtual worlds: The design, use, and influence of voice chat in online play. *Human–Computer Interaction*, 30(3-4):336–365, 2015.

[39] S. Walkowski, R. Dörner, M. Lievonen, and D. Rosenberg. Using a game controller for relaying deictic gestures in computer-mediated communication. *International Journal of Human-Computer Studies*, 69(6):362–374, 2011.

[40] N. Wong and C. Gutwin. Where are you pointing?: The accuracy of deictic pointing in CVEs. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '10, pages 1029–1038, New York, NY, USA, 2010. ACM.

[41] N. Wong and C. Gutwin. Support for deictic pointing in CVEs: Still fragmented after all these years'. In *Proceedings of the 17th ACM Conference on Computer Supported Cooperative Work & Social Computing*, CSCW '14, pages 1377–1387, New York, NY, USA, 2014. ACM.

[42] J. P. Zagal, J. Rick, and I. Hsi. Collaborative games: Lessons learned from board games. *Simul. Gaming*, 37(1):24–40, Mar. 2006.

[43] A. Zutshi and G. Sharma. A study of virtual environments for enterprise collaboration. In *Proceedings of the 8th International Conference on Virtual Reality Continuum and its Applications in Industry*, pages 331–333. ACM, 2009.