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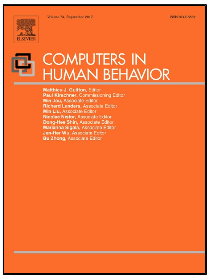

From Road Distraction to Safe Driving: Evaluating the Effects of Boredom and Gamification on Driving Behaviour, Physiological Arousal, and Subjective Experience

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From Road Distraction to Safe Driving: Evaluating the Effects of Boredom and Gamification on Driving Behaviour, Physiological Arousal, and Subjective Experience

Abstract

Boredom and low levels of task engagement while driving can pose road safety risks, e.g., inattention during low traffic, routine trips, or semi-automated driving. Digital technology interventions that increase task engagement, e.g., through performance feedback, increased challenge, and incentives (often referred to as 'gamification'), could therefore offer safety benefits. To explore the impact of such interventions, we conducted experiments in a high-fidelity driving simulator with thirty-two participants. In two counterbalanced conditions (*control* and *intervention*), we compared driving behaviour, physiological arousal, and subjective experience. Results indicate that the gamified boredom intervention reduced unsafe coping mechanisms such as speeding while promoting anticipatory driving. We can further infer that the intervention not only increased one's attention and arousal during the intermittent gamification challenges, but that these intermittent stimuli may also help *sustain* one's attention and arousal in between challenges and throughout a drive. At the same time, the gamified condition led to slower hazard reactions and short off-road glances. Our contributions deepen our understanding of driver boredom and pave the way for engaging interventions for safety critical tasks.

1. Introduction

More than one million people die in car crashes worldwide every year, and another twenty to fifty million are injured (WHO, 2015). Road crash statistics such as these offer evidence of the severe consequences resulting from human error, especially among young drivers. Recently, there has been an increase in people accessing social media and apps while driving (NHTSA, 2016; Vollrath, Huemer, Teller, Likhacheva, & Fricke, 2016). One of the causes for such distractions may be boredom, i.e., situations in which engagement in the driving task is low. This low engagement can occur, e.g., on familiar routes, in low traffic, or on long distance drives (Schroeter, Oxtoby, Johnson, & Steinberger, 2015). Driver boredom may also trigger equally dangerous risk taking behaviours, such as speeding (Steinberger, Moeller, & Schroeter, 2016). Semi-automated driving further decreases engagement in the driving task, yet requires drivers to remain vigilant and take over control at any time (Casner, Hutchins, & Norman, 2016; Walch et al., 2017), amplifying the unsafe effects of driver boredom.

Humans perform a task best (and safest) when they are adequately engaged in the task (Csikszentmihalyi, 1997; Yerkes & Dodson, 1908). Therefore, to limit driver boredom and safety risks while driving, Heslop et al. (2014) and Schroeter et al. (2014) proposed to develop and have been testing interventions that encourage engagement in the driving task. Studies by Markey et al. (2014) revealed four generally effective strategies associated with heightened task engagement: increase challenge, offer performance feedback, provide social approval, and give incentives. Putting these strategies to advantage is often referred to as gamification, commonly defined as 'the use of game design elements in non-game contexts' (Deterding, Dixon, Khaled, & Nacke, 2011). As explained by Chou (2015), this term is used, because games are valuable sources of insight and understanding into how to keep people consistently engaged with repetitive activities. Applying gamification has been shown to increase engagement in various settings such as education and health (for reviews, see Hamari, Koivisto, & Sarsa, 2014; Seaborn & Fels, 2015). As such, increasing the stimulus of the driving task itself through gamification can address safety risks caused by boredom and disengagement (Schroeter et al., 2014).

The aims of this study were to deepen our understanding of driver boredom and to investigate the impact of gamified driving on road safety and task engagement. To address these research aims, we sought to answer the following research questions.

- *RQ1:* How do boredom and gamified driving affect vehicle control and safety?
- *RQ2:* What are the effects of boredom and gamified driving on psychophysiological aspects of arousal?

The contribution of our work is threefold. First, we introduce a boredom induction useful to experimentally investigate driver boredom, as well as a boredom intervention. Second, we present new empirical data from a driving simulator study examining objective and subjective measures of safety and boredom. Finally, we offer methodological insights from our study into this subjective experience and discuss the intertwined, escapist responses we received. These contributions are timely as there is increased attention in both human-computer interaction and psychology on the use of mobile devices and applications in the car (Normark, 2015), on keeping drivers in the loop in increasingly automated cars (Casner et al., 2016), and on better understanding a driver's physiological responses in relation to mental states (Wickens, Hollands, Banbury, & Parasuraman, 2015).

2. Related Work

2.1. Driver Boredom

Boredom is often defined as 'the aversive experience of wanting, but being unable, to engage in satisfying activity' (Eastwood, Frischen, Fenske, & Smilek, 2012, p. 483). Toohey (2011) explains that boredom generally derives its force from predictability, monotony, confinement, excess, and repetition, which are characteristic of the driving task. Driving situations that give rise to boredom include low traffic, slow or constant speed, and routine drives – with subjective experiences such as discomfort, mind wandering, frustration, and 'being on autopilot' commonly experienced (Steinberger, Moeller, et al., 2016). Coping mechanisms manifest themselves in *approach* strategies related to the driving task such as speeding, which are often dangerous, and *avoidance* strategies, which include phone use. Young drivers and people who are less conscientious and less enthusiastic about driving are more likely to suffer driver boredom (Heslop, 2014).

Kurzban et al. (2013) put forward a comprehensive theory describing that states such as boredom promote the efficient use of mental resources. In this theory, called *opportunity cost model of subjective effort and task performance,* the authors argue that these states resulted from an evolutionary process. A cost-benefit analysis may promote re-allocation of resources from the task at hand to a more valuable task. This impairs the performance of the former task. Therefore, to sustain or increase task engagement in the driving context, it seems promising to enhance (or add value to) the primary driving task *itself.*

Studies that particularly explore driver boredom and its impact on driving behaviour are scarce. Furthermore, there is a lack of recommendations and experiences regarding the methodological complexities in undertaking such experimental research. Our study aims to address these research gaps.

2.2. Boredom Interventions

In line with the *opportunity-cost-model*, Markey et al. (2014) explored four determinants of value, i.e., manipulations of boredom. These are: increased challenge, performance feedback, social observation, and rewards. All four strategies have been shown to relate to increased task engagement (A. R. Markey, 2014), feelings of competence (Deci, Vallerand, Pelletier, & Ryan, 1991), and a sense of progress (Loewenstein & Prelec, 1993). Putting these strategies to advantage is often referred to as gamification (Deterding et al., 2011).

Many drivers already come up with challenges themselves, when they do not feel sufficiently engaged. They artificially increase difficulty to optimise their driving style and keep themselves entertained, e.g., by anticipating the right point in time to start coasting while approaching a red light, ideally allowing sufficient time for the lights to turn green (Steinberger, Moeller, et al., 2016; Steinberger, Schroeter, Foth, & Johnson, 2017). Such activities are highly contextual, depending on, e.g., traffic or upcoming road signs.

Related work both in industry and academia produced gamified driving applications (for reviews, see Diewald, Möller, Roalter, Stockinger, & Kranz, 2013; Vaezipour, Rakotonirainy, & Haworth, 2015). For example, GoFar[1] logs harsh accelerations, fuel intake, etc., to indicate inefficient driving and to display the user's performance on leaderboards. Such apps provide after-the-fact feedback and do not take into consideration the driving context to increase task engagement. Uniquely, we explore the nature and repercussions of immediate, context-aware interventions, e.g., by offering driving challenges. While others developed concepts of digital entertainment content to bored drivers (Krome, Holopainen, & Greuter, 2017; Prokhorov, Kalik, & Varri, 2011), these concepts did not take into account cognitive, manual, or visual distraction. In contrast, our study uniquely investigates whether the driving task *itself* can be made more engaging through gamification.

Besides this lack of context-aware boredom interventions, there is a shortage of literature reporting empirical data from gamified driving studies. Irrespective of whether applications provide feedback in-situ or post-drive, gamified driving requires extensive user testing (Diewald et al., 2013). In particular, more work is needed to understand the impact of gamified driving on behaviour, task engagement, and boredom in this safety-critical space – another gap our study aims to address.

3. Method

3.1. Apparatus

The study took place in an advanced moving-base driving simulator, which presents a safe, yet immersive way to conduct controlled lab experiments. This simulator consists of a complete car body, being a Holden Commodore with an automatic transmission, mounted on a motion platform. The platform allows for six degrees of freedom to reproduce movement appropriate to the driver's manoeuvres and varying road surfaces *(Figure 1)*. The virtual road environment is projected onto three screens (4 m in width, 3 m in height) providing a 180 degree field of view and onto LCD monitors that simulated side and rear view mirrors. Surround sound for engine and environmental noise is provided via speakers mounted in the car. Research data collected from the driving simulator was sampled at 20 Hz (cf. *Driving Behaviour Measures)*.

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[1] http://shop.gofar.co/

Figure 1: The driving simulator from a participant's perspective (left) and from within the researchers' control room (right).

3.2. Driving Scenario and Boredom Induction

Previously identified well-performing boredom inductions, such as the virtual peg turning task (A. Markey, Chin, Vanepps, & Loewenstein, 2014), are not applicable in the car, so we needed to operationalise an appropriate one for the driving simulator. It has been suggested to identify key characteristics of driving scenarios that cause particular phenomena and to then model these conditions within the simulated environment (e.g., Takayama & Nass, 2008). We therefore implemented low traffic, slow and constant speeds into the simulated road environment. A sense of routine driving was instilled by getting participants to complete the same road network four times (two practice drives, two research drives), and the vehicle featured automatic transmission, all of which are associated with boredom (Steinberger, Moeller, et al., 2016). Lastly, participants drove by themselves, since a lack of social interaction is linked to boredom as well (Martin, Sadlo, & Stew, 2006).

In the resulting road scenario, adapted from a related study (Steinberger, Proppe, Schroeter, & Alt, 2016), participants would drive for sixteen minutes to complete one trip and encounter eleven speed signs on the way. At the beginning of the drive, participants were instructed to go straight at all intersections during their 13km drive, which consisted of suburban and town roads as well as dual carriageways *(Figure 2)*. Oncoming traffic consisted of 2-3 cars per minute. While the driving scenario could have been made even more boring by removing buildings or oncoming traffic, we decided against this as that would have come at the expense of realism. We wanted to strike a balance between a boredom inducing and realistic experience.

Figure 2: Road scenario screenshot.

To validate the effectiveness of this boredom induction, the road scenario was pilot tested by nine participants (three female; aged *M*=27.9, *SD*=3.0; driving experience in years *M*=8.3, *SD*=3.7). Following Markey et al. (2014), we administered a post-hoc survey, a short form of the Differential Emotion Scale (Gross & Levenson, 1995), to determine boredom discreteness. Seven of the nine pilot participants indicated boredom as the highest emotion they experienced, resulting in a 77% discreteness. This result sits above the discreteness percentages (55-72%) found by Markey et al. in their boredom tasks. We concluded that our road scenario presented a reliable way to induce boredom more than any other emotion.

3.3. Boredom Intervention

The study's boredom intervention, called *CoastMaster,* is a mobile application and ran on a 4.7-inch smartphone held by a mounting bracket on the windscreen *(left in Figure 1)*, in accordance to local road regulations[2]. *CoastMaster* was an outcome from an iterative design, prototyping, and development process previously presented by Steinberger (2017), building upon game design (Steinberger et al., 2015), real-time driving data (Steinberger, Schroeter, & Babiac, 2017), and ambient interface design (Steinberger, Proppe, et al., 2016).

The application served two purposes: 1) it functioned as an ambient speedometer, and; 2) it encouraged anticipatory driving by gamifying transitions to new speed limits. The latter rewarded coasting down to new speed limits without unnecessary pedal usage, similar to related work by Ecker et al. (2011). The objectives of the application were: first, to stay within the speed limit (avoid speeding), and; second, to do so with limited pedal usage even when the speed limit is changing.

Overall, the design of *CoastMaster* presented a complex challenge to strike a careful balance between engagement in the driving task and visual distraction. Note that driving is a highly visual task (Sivak, 1996), and *CoastMaster* provides immediate visual feedback while the vehicle is in motion. The literature around ambient interface design provided a useful perspective on this requirement. Based on ambient interface design recommendations (Mankoff et al., 2003) and previous evaluations (Steinberger, Proppe, et al., 2016), we further reduced visual clutter and sudden interface changes compared to previous versions. We used dominant colours and simple shapes, as well as smooth fade-in and fade-out transitions between them. This change of colours and shapes was designed to avoid sudden appearances or changes in the visual peripherals, which, as per information visualisation and perception theory (Ware, 2012), would unwantedly draw the user's attention from the road towards the intervention. Furthermore, since some participants were irritated by sound elements employed in our previous prototype evaluation, all sound was turned off in this study.

The ambient speedometer is illustrated in *Figure 3*. In the depicted example the current speed limit is 40 km/h. Blue background colour visualises staying below the speed limit, purple background colour visualises driving at the speed limit, and red background colour visualises driving above the speed limit. The height of this colour shape increases as the speed increases. Our iterative process, which was further reported by Steinberger et al. (2016), resulted in a design similar to the digital speedometer proposed by Smith et al. (2014), which we were unaware of at the time. This may suggest a level of maturity in the design of this particular use case and called for an evaluation of its use, which Smith et al. did not report.

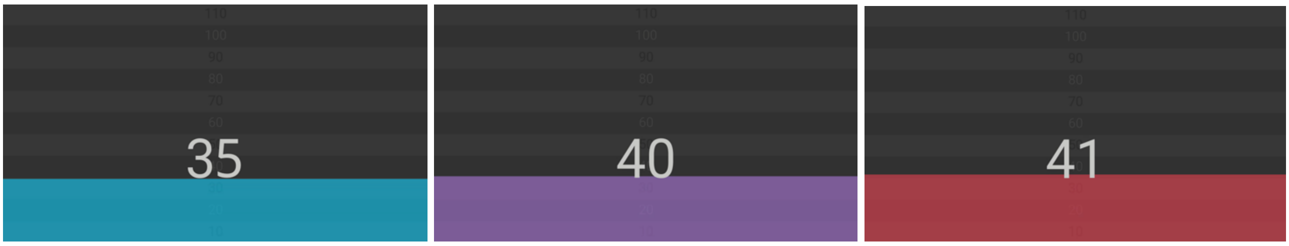

Figure 3: *CoastMaster* serving as an ambient speedometer in a 40 km/h zone.

The gamified transitions to new speed limits are illustrated in *Figure 4*. For example, the goal of the challenge may be to coast-down from 80 km/h to a new speed limit of 60 km/h. Upon approaching a lower speed limit, a visual icon signals the beginning of a challenge *(Figure 4a)*. During the coast-down phase, a vertical bar will move across the screen representing the remaining distance to the approaching speed sign *(Figure 4b)*. The colour of this vertical bar visualises pedal use, i.e., using no pedal (blue) or using the brake or accelerator pedal (red). Once the speed sign has been passed, the application will display an assessment of the user performance. Blue or red background colours signify arriving at the new limit (challenge succeeded) and exceeding the new speed limit (challenge failed) respectively. A reference line allows users to assess their own coasting performance, and up to three stars visualise the extent of smooth coasting, i.e., lack of pedal use *(Figure 4c)*.

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[2] https://www.qld.gov.au/transport/safety/road-safety/mobile-phones/

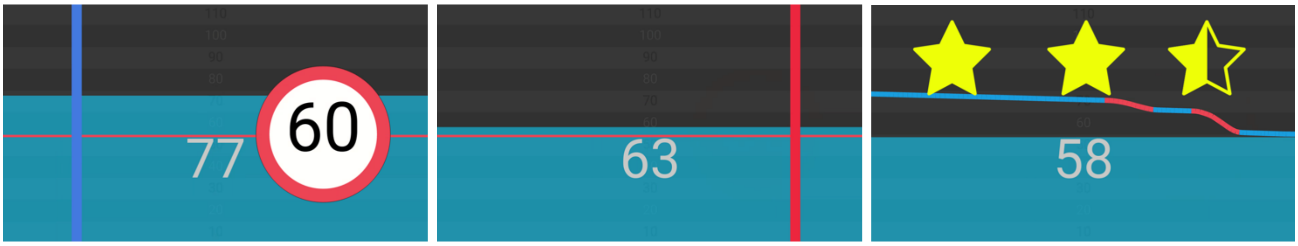

Figure 4a: Start of a new coasting challenge (80 km/h zone to 60 km/h zone).
Figure 4b: During challenge. **Figure 4c:** End of challenge.

3.4. Study Design

We designed the study as a within-subjects, repeated measures experiment with two counterbalanced conditions across participants, *control* and *intervention*, with approximately sixteen minutes of driving per condition. Participants were randomly assigned to begin with one of these conditions. During each condition participants would encounter eleven speed limit signs that resulted in six slow-down transitions, i.e., six *CoastMaster* challenges in the *intervention* condition.

3.5. Sample

Thirty-two drivers participated in the study, in line with similar sample sizes in related driving simulator studies (Saifuzzaman, Haque, Zheng, & Washington, 2015; Savage, Potter, & Tatler, 2013/2). Participants were recruited via email, social media, and in person on our university campus. Seven participants had already participated in one of our previous studies around related topics. We deliberately recruited young male adults aged 18 to 25, since research confirmed that they are especially susceptible to crashing (WHO, 2015), risky driving (Watson, Watson, Siskind, & Fleiter, 2009), phone distractions (Neyens & Boyle, 2007), and feeling disengaged (Drory, 1982). The pre-existing interest in digital games prevalent in this demographic (Brand, Lorentz, & Mathew, 2014) made exploring gamification particularly promising, and the boredom intervention came out of a process focussing on this target audience (Steinberger, Schroeter, Foth, et al., 2017).

3.6. Procedure

Before commencing data collection, approval to conduct the study was granted from the university's human research ethics committee (approval number 1500000046), and written consent was obtained from all participants. Upon arrival at the driving simulator, participants entered the preparation room, where they were briefed on the experiment procedure and the tasks they were to undertake. In the following twenty minutes *(Figure 5)*, participants were fitted with two devices used to record their electrodermal activity (EDA) and their cardiac activity (using electrocardiography; ECG). Participants were not permitted to take their personal mobile phone into the driving simulator.

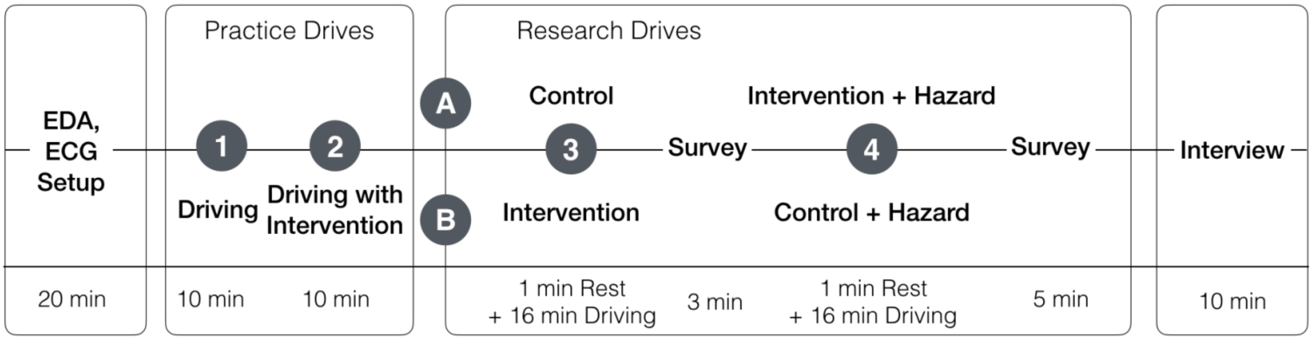

Figure 5: Timeline of the experiment (excluding instructions and simulator operation procedures in between).

The first task was to complete a ten-minute practice drive to become familiar with the vehicle *(Figure 5 – 1 Driving)*. At the end of this first practice drive the Simulator Sickness Questionnaire (Brooks et al., 2010) was verbally administered to identify possible nausea and determine if the participant was able to continue the testing session. Before the second practice drive, the functionality of *CoastMaster* was explained and the smartphone in the vehicle was turned on. Participants were then able to familiarise themselves with the application *(Figure 5 – 2 Driving with Intervention)*. Before commencing each of the two subsequent research drives, participants were offered some water and asked to rest for a minute. Depending on the condition, the smartphone was then turned off *(Figure 5 – A3 Control)* or the application restarted *(Figure 5 – B3 Intervention)*. After completion of each research drive, participants were asked to complete a survey on a tablet, which was placed on the passenger seat.

At the end of the final condition *(Figure 5 – A4, B4)*, participants encountered a hazard in form of a pedestrian. The pedestrian would unexpectedly appear from behind a school bus and cross the road *(Figure 6)*. This hazard occurred during a speed limit transition from 60 km/h down to 40 km/h, i.e., during a coasting challenge in the *intervention* condition *(Figure 5 – A4)*. The hazard served two purposes. First, it would allow us to see participants' responses in a critical situation during the use of the intervention. Second, the physiological and subjective data in response to the hazard would represent an extreme situation with high levels of stimulation and assist us in better understanding the data overall. We deliberately introduced the hazard at the end of the final drive to avoid disrupting the induced boredom state, similar to Klarkowski et al. (2016).

Figure 6: At the end of the final drive, a pedestrian hazard unexpectedly appeared from behind the school bus in the middle of a speed limit transition (i.e., coasting challenge in *intervention*).

Finally, at the end of the driving session all electrodes were removed from the participant in the preparation room, and the experiment concluded with a semi-structured post-hoc interview. As a compensation for their time, each participant was given an AUD 75 gift card. The study took approximately 2.5 hours for each participant.

3.7. Measures

It is generally accepted that multi-measure studies are more comprehensive (Hunsley & Meyer, 2003; Stern, Ray, & Quigley, 2001). Thus, the current study used driving behaviour, physiological arousal, and subjective experience measures to assess the research questions.

3.7.1. Driving Behaviour Measures

Road lane position: We recorded in meters the lateral shift of the vehicle relative to the road centre and devised the standard deviation of this shift as a metric for safe and attentive driving (Green, 2009). We used this metric to see if the added intervention has any effects on lateral control.

Driving speed: Driving speed was recorded in km/h and used to examine the impact on anticipatory driving, speeding violations, and hazard responses.

Observations: We captured participants' eye glances, boredom responses, and hazard reactions using video footage from an in-vehicle camera as well as worksheets.

3.7.2. Physiological Arousal Measures

Two physiological measures of arousal, electrodermal activity (EDA) and cardiac activity (ECG), were recorded continuously throughout the driving simulation, without interrupting the induced boredom state (cf. Bellotti, Kapralos, Lee, Moreno-Ger, & Berta, 2013; Yannakakis, Martinez, & Garbarino, 2016). The Biopac BioNomadix[3] MP150WSW system was used with BN-PPGED and BN-ECG2, which are wearable transmitters that wirelessly sent data to the data acquisition unit, which in turn was secured in the boot of the vehicle.

Electrodermal activity (EDA): EDA reflects the increase of sweat production in the eccrine glands when the central nervous system becomes activated, which results in measurable changes in the conductivity of the skin. It is thought of as a measure of an individual's emotional and cognitive activity responding to experiencing arousal (Boucsein, 1992; Siddle, 1991). Research has shown EDA to be highly correlated with self-reported arousal (Cacioppo, Tassinary, & Berntson, 2007) and to be a promising measure to detect arousal in driving simulator studies (Reimer & Mehler, 2011).

In our study, EDA was measured using two Ag/AgCl disposable snap electrodes (Biopac Systems, Goleta, CA, USA) filled with a 0.05 M sodium chloride electrolyte gel. Exosomatic electrodermal activity was measured with a constant voltage of 0.5 V and was sampled at 500 Hz. EDA electrodes are most commonly measured at fingertips or palms (Kappeler-Setz et al., 2011), which participants would use for steering. Van Dooren et al. (2012) have shown that measurements at the foot were the best alternative to fingers or palms, which are subject to potential increase in motion artefacts while using a steering wheel. Therefore, EDA activity was measured from the inner arch of the left foot, which participants would not need to move in an automatic transmission vehicle.

Electrocardiography (ECG): ECG is the process of recording electrical changes associated with cardiac activity. Cardiac activity is controlled by sympathetic and parasympathetic activity of the autonomic nervous system. The relationship between these two can be quantified by measuring the time between successive heartbeats, known as the R-R interval. ECG is a common measure for arousal (Cacioppo et al., 2007) and has been used in driving studies. Reimer and Mehler (2011) found drivers' elevated HR to be a reliable indicator of increased arousal, and they suggested heart rate variability (HRV) to be an appropriate measure for fatigue related research or long duration driver interactions. HRV is used as a measure of physiological arousal, with shorter duration of the interval indicating increased arousal (Roscoe, 1992). The ECG signal was recorded from a two-lead montage with one electrode placed approximately five cm below the right clavicle and the second electrode placed on the V6 location (i.e., left midaxillary line) and was sampled at 500 Hz. The extraction of the R-R interval data was performed with AcqKnowledge 4.4 (Bipoac Systems, Goleta, CA, USA).

3.7.3. Subjective Experience Measures

An epistemological issue with physiological measures is that they are indicative of any number of psychological constructs, e.g., excitement, frustration, or boredom (Blascovich, 2000; Cacioppo et al., 2000). That is, they are largely unable to infer one specific psychological state from one physiological response. A combination of methods

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[3] Biopac Systems, Goleta, CA, USA, https://www.biopac.com/product-category/research/bionomadix-wireless-physiology/

yielding both objective and subjective data can substantiate interpretations while still benefitting from replicability at the same time (Creswell, 2013; Yamaguchi, Wakasugi, & Sakakima, 2006). To that end, surveys and interviews were conducted to complement and better contextualise the physiological data. To assess participants' subjective experience during the two conditions, four types of data (described below) were collected. An additional survey asked about demographic information and previous driving experience.

Boredom intensity: Boredom intensity was assessed by a seven-item subset (previously used by Markey et al. (2014)) of the Multidimensional State Boredom Scale (MSBS) (Fahlman, Mercer-Lynn, Flora, & Eastwood, 2013). Participants indicated their agreement to the items on a seven-point Likert-scale (1: strongly disagree; 7: strongly agree). Example items include *"Time was passing by slower than usual," "Everything seemed repetitive and routine to me," "I wished I were doing something more exciting."* An overall boredom intensity score was produced by averaging the responses to the seven items. Gutwin et al. (2016) found that participants' recollection of an experience is influenced by the peak and final moments of that experience. Therefore, we report on the subset of drives that did not end in encountering the hazard.

Arousal: In terms of subjective arousal, the Self-Assessment Manikin (SAM) (Bradley & Lang, 1994) was used. SAM is a pictorial self-report measure, in which participants indicate their emotional state by selecting a figure that most closely represents that state. Again, we excluded hazard drives from the reported results.

Perceived driving performance: The survey concluded with statements regarding perceived speed keeping, perceived lane keeping, perceived safe driving. Each was an item on a seven-point Likert scale with higher scores indicative of better performance.

Interviews: Semi-structured interviews were conducted to allow participants to comment on their experience and for us to touch upon potentially unexpected behaviours. Notes and audio recordings were taken during the interviews.

3.8. Data Analysis

Driving log files were cleaned to exclude irrelevant data at the beginning and end of the recording and to remove erroneous data points in relevant categories (e.g., negative values in driving speed). The physiological data set was visually scanned to remove movement artefacts.

A Grubbs' test (Grubbs, 1950) revealed one participant (P6) to be a significant ($p < 0.05$) outlier in terms of driving speed in a way that could not represent regular driving behaviour. Since driving speed is strongly correlated with all measures, P6 was excluded from further analyses.

Statistical analysis was based on methods proposed by Wobbrock and Kay (2016). We report effect sizes (Cohen's d) to provide an indication of the magnitude of the effect on driving behaviour attributed to the intervention. Unlike p-values in significance testing (which we report on as well), effect sizes are independent of sample sizes and present valuable insights to interpret the findings. Following Cohen (1992), we treat effect sizes of 0.2 – 0.5 as small, 0.5 – 0.8 as medium, and greater than 0.8 as large.

The qualitative interview responses were analysed based on thematic coding methods to tease out commonalities and patterns within the data, as proposed by Miles et al. (2013).

4. Results

4.1. Sample Details

Demographic information: Participants were male and aged 18 to 25 (M=20.6 years, SD=2.1). Twenty-one participants self-reported their nationality to be Australian, while the remaining eleven participants were from eleven different countries (five from Europe, four from the Asia-Pacific, one from Brazil, one from South Africa). With respect to the highest level of completed education, twenty-two participants indicated high school, five participants reported a bachelor's degree, and the remaining five participants indicated other types of certificates or diplomas.

Driving experience: Participants had between one and eight years of driving experience (M=3.9, SD=1.8). Sixteen participants were on a provisional driver's license, while the remaining sixteen participants were on an open driver's license, which means all participants were allowed to drive without supervision. Twelve participants indicated making fewer than five trips per week, twelve indicated making between five and fifteen trips, and eight participants indicated making more than fifteen trips per week.

4.2. Driving Behaviour Results

Speed control: Comparisons between the conditions for the speeding measures can be seen in *Table 1.* A number of significant comparisons were found. These included the overall driving speed, speeding percentage, speeding intensity, speed during speed limit transitions, approaching speed change (anticipation), and passing speed change variables – whereby the speed was lower in the *intervention* condition or the reduction in speed was greater in the *intervention* condition than in the *control* condition. The majority of the effect sizes are small to medium. Although not significant, participants in *control* took less time to slow down as the hazard occurred.

Measure	**Road segment**	***M* (*SD*), Control**	***M* (*SD*), Intervention**	**Statistical test**	**Effect size Cohen's *d***
Driving speed (km/h)	Overall	53.99 (2.78)	53.68 (4.00)	$Z=-2.54^{**}$	0.09
Speeding percentage (%)	Overall	34% (0.24)	28% (24)	$Z=-2.53^{**}$	0.25
Speeding intensity (km/h)	When speeding	2.05 (1.71)	1.32 (1.26)	$Z=-3.66^{***}$	0.48
Driving speed (km/h)	Speed limit transitions	51.49 (3.64)	49.85 (3.12)	$Z=-4.31^{***}$	0.49
Speed reduction (km/h) (anticipation)	While approaching speed signs	-2.15 (2.55)	-3.37 (2.70)	$t=-4.38^{***}$	0.46
Speed reduction (km/h)	While passing speed signs	0.21 (3.33)	-0.94 (2.65)	$Z=-2.61^{***}$	0.38
Speed reduction (km/h)	0-5 sec after passing speed signs	-0.32 (2.73)	-0.64 (2.38)	$Z=-0.06$	0.13
Speed reduction (km/h)	0-20 sec after passing speed signs	-0.56 (2.48)	-1.14 (1.68)	$Z=-1.165$	0.27
Driving speed (km/h)	While the hazard appears	46.04 (5.97)	44.9 (4.25)	$U=106$	0.22
Time to slow-down to 5 km/h (sec)	After the hazard appeared	2.57 (1.30)	3.11 (1.54)	$U=60$	0.38

$^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.
Z: Wilcoxon signed-ranks test; t: paired samples t-test; U: Mann-Whitney test.

Table 1: Results related to driving speed.

The measures overall and for specific road segments in *Table 1* are:

- *Overall driving speed*: The mean driving speed (in km/h) across the entirety of the road network (except for the final speed limit transition, which included the hazard).
- *Speeding percentage*: time spent driving above the posted speed limit divided by the overall time spent driving.
- *Speeding intensity*: while speeding, the absolute amount of speed (in km/h) over the posted speed limit.
- *Speed during speed limit transitions*: driving speed in (km/h**)** during speed limit transitions, i.e., during coasting challenges in the *intervention* condition.
- *Speed reduction while approaching speed signs (anticipation)*: the absolute amount of speed (in km/h) under or over the previously posted speed while approaching a new speed sign.
- *Speed reduction while passing speed signs*: the absolute amount of speed (in km/h) under or over the newly posted speed while passing the new speed sign.
- *Speed reduction after passing speed signs*: change in driving speed 5 sec or 20 sec after the speed sign.
- *Speed while hazard appears*: driving speed (in km/h) when the hazard first appears.
- *Hazard, time to slow-down to 5 km/h*: time taken (in sec) to slow down to 5 km/h or less.

Lateral control: *Table 2* shows comparisons between the conditions for the lateral control. One small effect was found (for lane keeping during straight and slow road segments), but no significant comparisons. It is worth noting that lane control in *intervention* was never worse than in *control*.

Road segment	***M* (*SD*), Control**	***M* (*SD*), Intervention**	**Statistical test**	**Effect size Cohen's *d***
Straight 40 km/h zones	0.17 (0.07)	0.16 (0.05)	*Z*=-0.31	0.21
Speed limit transitions	0.13 (0.07)	0.12 (0.07)	*Z*=-0.52	0.04
0-5 sec after passing speed signs	0.06 (0.04)	0.07 (0.06)	*Z*=-0.31	0.06
0-20 sec after passing speed signs	0.12 (0.06)	0.12 (0.06)	*Z*=-0.38	0.03

Table 2: Results related to lateral control: Standard deviation (SD) of lateral shift from the road centre in meters (excluding the final speed limit transition, which contained the hazard).

Eye glances: Eye glances towards the smartphone were recorded for seventeen participants (only in the *intervention* condition, since the smartphone was not turned on in the *control* condition). Towards the ambient speedometer, there were *M*=0.72 (*SD*=1.36) long glances (two seconds or longer). During gamified challenges, there were *M*=2.28 (*SD*=2.65) long glances and *M*=16.22 (*SD*=6.55) short glances (less than two seconds) towards the smartphone.

Boredom response: Six participants (P6, P16, P18, P25, P26, P29) engaged in singing, whistling, and talking to themselves. Another recurrent behaviour was deliberate casual or risky driving, e.g., driving with just one finger (P17, P25), lane swerving (P17, 29), harsh accelerations (P29), cruising with the window down and resting elbows (P21, P32), and steering with the knees (P6). Drumming, fidgeting, biting fingernails, and leg wiggling (P3, P6, P7, P16, P25, P26) were widespread as well, as were looking out the window (P3, P6, P13, P17, P29) and eating or drinking (P6, P22, P25, P32). Four participants (P7, P12, P13, P22) exhibited slow eye blinking and yawning. Many of the observed behaviours, e.g., resting elbows, eyes that stare into infinity, and yawning, are telltale signs of boredom (Toohey, 2011).

Hazard response: The hazard event was the only time when participants experienced harsh braking. As a result, the motion platform jolted the vehicle forward and subsequently participants needed to compose themselves. Nineteen participants expressed their surprise, many of whom vocally, e.g., *"oh my god, a kid"* (P22). Fifteen participants double checked their mirrors and scanned the environment for further hazards.

4.3. Physiological Arousal Results

We report on tonic (overall) and phasic (individual events) results from the EDA (*N*=24) and ECG (*N*=31) data. Eight participants had to be excluded from the EDA analysis due to technical issues in capturing that data (P4, P5, P8, P15, P22, P25, P27) and, as mentioned, one outlier (P6) was excluded from both EDA and ECG.

EDA: Comparisons between the conditions for EDA can be seen in *Table 3*. Two medium effects and one small effect were found for the hazard indices, but no significant comparisons. EDA generally increased during higher stimulation.

Road segment	***M* (*SD*), Control**	***M* (*SD*), Intervention**	**Statistical test**	**Effect size Cohen's *d***
Overall (tonic)	5.12 (2.31)	5.39 (2.22)	*Z*=-1.31	0.12
Straight 40 km/h zones	4.99 (2.3)	5.24 (2.16)	*Z*=-1.46	0.12
Speed limit transitions	4.99 (2.32)	5.37 (2.24)	*Z*=-1.57	0.17
0-5 sec after passing speed signs	5.07 (2.35)	5.43 (2.22)	*Z*=-1.66	0.16
0-20 sec after passing speed signs	5.06 (2.31)	5.41 (2.21)	*Z*=-0.38	0.15
Hazard	4.16 (1.92)	5.46 (2.57)	*U*=47	0.57
0-5 sec after hazard	5.41 (2.3)	7.19 (3.08)	*t*=-1.62	0.66
0-20 sec after hazard	6.56 (3.00)	7.68 (3.47)	*t*=-0.85	0.35

Table 3: EDA in microsiemens (µS)
(excluding the final speed limit transition, which contained the hazard).

ECG: *Table 4* shows comparisons between the conditions for the R-R responses. Two medium and one small effect for the hazard indices, but no significant comparisons were found. R-R levels stayed about the same across conditions, except for the hazard section where R-R intervals were longer (i.e., slower heart rates) in *intervention*.

Road segment	***M* (*SD*), Control**	***M* (*SD*), Intervention**	**Statistical test**	**Effect size Cohen's *d***
Overall (tonic)	0.79 (0.11)	0.79 (0.11)	*t*=-0.24	0.07
Straight 40 km/h zones	0.79 (0.11)	0.80 (0.11)	*t*=-0.11	0.03
Speed limit transitions	0.79 (0.11)	0.79 (0.11)	*t*=0.01	0
0-5 sec after passing speed signs	0.77 (0.10)	0.77 (0.11)	*t*=-0.11	0.03

0-20 sec after passing speed signs	0.77 (0.10)	0.78 (0.11)	*t*=-0.07	0.02
Hazard	0.78 (0.12)	0.83 (0.13)	*t*=-1.25	0.45
0-5 sec after hazard	0.68 (0.09)	0.74 (0.12)	*t*=-1.48	0.53
0-20 sec after hazard	0.73 (0.13)	0.76 (0.13)	*t*=-0.83	0.3

Table 4: Results related to ECG: R-R intervals in seconds
(excluding the final speed limit transition, which contained the hazard).

4.4. Subjective Experience Results

Surveys: *Table 5* shows the subjective experience results of the post-hoc surveys. One statistically significant comparison was found related to speed keeping, which was perceived to be better in *intervention*. A medium effect suggests that the intensity of boredom was reduced in the *intervention* drives.

Measure	***M* (*SD*), Control**	***M* (*SD*), Intervention**	**Statistical test**	**Effect size Cohen's *d***
Boredom intensity (excl. hazard drives) (Cronbach's α=0.88)	4.31 (1.23)	3.84 (1.09)	*U*=86	0.4
Subjective arousal (excl. hazard drives)	1.75 (0.96)	1.82 (1.1)	*U*=118	0.07
Perceived speed keeping	4.32 (1.33)	4.81 (1.3)	*Z*=-1.95*	0.37
Perceived lane keeping	5.13 (1.43)	5.13 (1.18)	*Z*=-0.17	0
Perceived safe driving	4.84 (1.37)	4.71 (1.44)	*Z*=-0.17	0.09

Table 5: Survey results reporting on participants' subjective experience after both counterbalanced conditions.

Boredom and task engagement: In the interviews, participants said the road scenario was *"repetitive"* (P7, P11, P15, P25), *"a bit slow"* (P18, P25), and that it was *"testing your patience"* (P23). Thirteen participants indicated they were used to this type of driving, e.g., on the highway or low traffic during night time. Regarding engagement during the *intervention* drive, participants said they *"paid more attention to speed limits and focussed more on road signs"* (P3, also P4, P27) and *"felt it went through faster, was more enjoyable and rewarding"* (P15). Others pointed out that the "*app gives you something to target"* (P6, P27) and that therefore it was *"more engaging"* (P24, P25) and *"less boring when approaching speed signs"* (P18).

Ambient speedometer: Thirteen participants emphasised that they liked ambient background colours, since these colours helped with speed control (P5, P8, P20, P21, P23, P24) and since participants were able to see them in their peripherals (P2, P3, P4, P9, P20, P28, P31). P21 said that, as a result, it felt *"more relaxing, as if someone else is watching the speed for [him]."* Strikingly, some participants appropriated the ambient speedometer to improve their own speed control. For example, P12 reported trying *"to stay at purple, which made speed keeping more engaging,"* and P14 *"kept an imaginary score for how long [he] could stay under red speed limit."* In contrast, P27 (also P31) pointed out that he *"usually wouldn't care if [his] driving speed was 5 [km/h] over,"* but the app was *"more strict."*

Coasting challenges: In terms of difficulty, participants sometimes found it *"challenging to anticipate"* (P7) when to start coasting, especially from higher speeds such as 80 km/h (P5). P25 suggested it would be harder when there were hills, and two participants (P27, P28) said they would like to see *"a similar strategy game for approaching red lights."* P20 and P22 reported the coasting challenges were easiest when they knew the upcoming speed changes from memory. P2 and P6 said that, to do well, it helped when they were sticking to the speed limit. Fifteen participants said they did not only glance at the stars to check their performance, but also tried to improve and achieve three stars, which made them *"happy."* While some participants were *"reward driven"* (P20), others were more curious about their braking pattern (P15). P15 was also hoping to see a trip average at the end. Conversely, participants reported feeling *"salty"* (P16), *"disappointed"* (P27), or *"frustrated"* (P32) when their driving performance did not result in three stars. Three participants (P13, P21, P24) reported not caring much for the stars or ignoring them. P9 reported *"coasting more for [himself] than for the game,"* during both drives, similar to P29 who reportedly was used to cruising down to stop at red lights.

Distraction: P7 felt he was *"more focussed on speed, less focussed on his surroundings"* and, referring to the red background colour, that *"it would be better to drive 1 km/h too fast than to be distracted from the road."* Similarly, P26 and P30 described the red colour as *"too harsh."* Five participants (P11, P12, P13, P14, P19) reported feeling visually distracted during the gamified coasting challenges, paying more attention to the phone rather than the road ahead. P22 (also P26) said the *"app distracted [him] from the pedestrian [hazard],"* and P21 said that *"it seemed as if the app was more focussing on slowing down than the road itself, e.g., in school zones."* Much of the visual distraction was appointed to the smartphone placement, which was considered distracting (P2, P9, P24) and out of visual field of view (P5).

5. Discussion

Returning to the research aim of furthering our understanding of driver boredom and the impact of gamified driving, we discuss our results in light of the two research questions and methodological limitations.

5.1. *RQ1:* How do boredom and gamified driving affect vehicle control and safety?

5.1.1. Speed Reduction and Anticipatory Driving

Overall speed reduction: Our data indicate that the gamified boredom intervention significantly reduced overall driving speed and speeding. In particular the intensity of speeding, which is an unsafe mechanism of coping with boredom (Steinberger, Moeller, et al., 2016), was significantly less pronounced in the *intervention* drives. The speed reduction was facilitated with the drivers interacting with the *Coastmaster* app, specifically the ambient speedometer, which resulted in more awareness of their driving speed. This utility of the ambient speedometer was further established via participants' interview responses according to which the ambient colours could be picked up in the peripherals as well as via the significantly improved perceived (self-report) speed keeping.

Anticipatory driving: The data further suggest the intervention improved anticipatory driving. This improvement was caused by the coasting challenges, which encouraged drivers to prepare for upcoming speed limit changes and rewarded them when they did. It is evidenced by effect sizes in speed control suggesting significantly earlier decelerations and significantly lower passing speeds in the *intervention* condition.

Toohey (2011, p. 174) explained that, above all, 'variety in experience' reduces boredom. Anticipatory driving and coasting may have provided such variety and replaced unsafe variety such as speeding.

Implications: These results present safety benefits, because speeding is a major and global contributor in the number and severity of road injuries (Global Road Safety Partnership 2008). It is well known that increased speed is associated with longer braking distances (Aarts & van Schagen, 2006) as well as increased severity of injury, especially with pedestrians (Kröyer, 2015/7). In addition to these safety benefits, lower driving speeds and smooth decelerations are linked to energy savings and reduced greenhouse gas emissions (Degirmenci, Katolla, & Breitner, 2015).

5.1.2. Distraction and Attention

Options to investigate attention and distraction include off-road eye glances, performance-related measures such as lateral control and hazard responses, and observed secondary activities.

Ambient speedometer not visually distracting: The study indicates that the ambient speedometer was not detrimental to visual attention towards the road environment. This is evidenced by the few (zero for many participants) long eye glances (> 2 sec) towards the smartphone when it served as an ambient speedometer.

Coasting challenges somewhat visually distracting: Long glances towards the smartphone were similarly low during coasting challenges. Findings from the 100-Car naturalistic driving study reveal that long glances (> 2 sec) increase the risk for having a near-crash or actual crash twofold (Klauer et al., 2006). However, in the current study during coasting challenges, it was observed that an average of sixteen short eye glances occurred suggesting a level of visual distraction. Again, the risk for crashing increases only minimally, when performing a single, short eye glance, to perform a simple secondary task such as adjusting the radio (Klauer et al., 2006). Even though our design placed emphasis on ambiently conveying information in such a way that it does not require explicitly looking at the smartphone screen, participants felt the need to do so, which could be attributed to three factors: 1) design was not ambient enough; 2) lack of familiarity and practice with the application; 3) positioning of the smartphone (i.e., although the smartphone was mounted against the windscreen in accordance with local road regulations, it required participants to glance slightly to their left).

The final coasting challenge included the pedestrian hazard and thus presented the highest stimulation during the entire experiment. The slower hazard reactions and less pronounced decelerations in the *intervention* condition might be explained by the many short glances towards the smartphone during the coasting. That is, participants who divided their visual attention between the road and the smartphone were less prepared to appropriately react to the pedestrian. The poorer hazard response might also be explained by cognitive distraction, i.e., through *CoastMaster*, participants had been conditioned to use their pedals scarcely. Thus, drivers might have hesitated to brake while thinking about the implications on the coasting challenge. Note, however, that the hazard section presented an extreme test. The pedestrian not only occurred during a coasting challenge, but also at an inconspicuous road section without corresponding signage or any visible foot traffic – a difficult test in terms of hazard perception skills (Grayson, Maycock, Groeger, Hammond, & Field, 2003).

Equally attentive lateral control: Our study revealed no undesirable effects of the *CoastMaster* app on lateral control, i.e., none of the participants drove off the road or deviated from their lane. This is evidenced by the data which showed no statistically significant difference between the two conditions. Interestingly, there was even a trend (interpreting the effect size) for *better* lateral control in *intervention* during straight, slow road sections, which are known to be associated with lower arousal levels (Desmond & Matthews, 1998). If lateral control is a metric for attentive driving, this would mean that the intervention helped participants to pay more attention to the driving task of steering. There may be several reasons to explain this trend. Perhaps drivers paid more attention during boring, straight segments due to the ongoing feedback from the ambient speedometer and the intermittent challenges brought the attention back to the primary driving task. Conversely, in *control,* participants might have been more inclined to, and occupied by, secondary tasks such as drumming or fidgeting, which may have had detrimental effects on lateral control.

Implications: We saw few long off-road eye glances caused by the intervention, but the many short glances during coasting challenges warrant further investigation into improving the user interface design, familiarisation with the intervention, and the positioning of the screen. More importantly though, we presented new safety benefits, because the study indicates that the intervention can increase and *sustain* a driver's attention during a 15-minute simulated drive. This is a promising finding in light of the motivation behind this work – reducing unsafe behaviours by making the driving task *itself* more engaging.

5.2. *RQ2:* What are the effects of boredom and gamified driving on psychophysiological aspects of arousal?

Higher arousal during challenges and in between challenges: The obtained effect sizes regarding EDA levels indicated a trend of increased physiological arousal in the *intervention* drives compared to the *control* drives. The same trend was visible in the self-reported boredom intensity and subjective arousal scores when excluding the hazard drives. Strikingly, the EDA levels indicated higher arousal in *intervention* than in *control* during the straight 40 km/h zones. This suggests that participants experienced higher levels of arousal *during* the intermittent gamification challenges and in between these intermittent stimuli as well. We can speculate that the intervention not only intermittently increased but also *sustained* one's stimulation during a 15-minute simulated drive. Assuming that secondary activities such as fidgeting or eating increased arousal in *control* as well, one could argue that this finding is even more remarkable.

EDA more telling than R-R-data of ECG: Contrary to the trends in EDA levels, no differences were found between the two conditions for the R-R data (bar the hazard section). Thus, EDA might be a more sensitive measure than the R-R index when assessing interventions for boredom.

A potential explanation for this lack of increased heart rate variability (HRV) arousal could be due to low cognitive workload. Previous work suggests that increases in mental workload result in significantly lower R-R indices (Fairclough, Venables, & Tattersall, 2005). Thus, with no difference in HRV when and when not using the app, these results suggest that the cognitive requirements needed are low. Further HRV spectral analyses might reveal more expressive signatures.

Furthermore, our findings mirror the work by Merrifield and Danckert (2014) who found that the physiological signature of boredom, compared to sadness, is characterised by elevated HR and concomitant lower EDA. This phenomenon of both decreased or stagnant as well as increased physiological arousal could be caused by directional fractionation and stimulus-response specificity (Stern et al., 2001). Physiological response directions are not uniform, and arousal brings about certain patterns of responding rather than increasing on a unidimensional continuum. As such, biosignals may vary with internal (e.g. mind wandering) and external (e.g., lane swerving, phone use) demands for attentional mental resources (Lacey & Lacey, 1970; Merrifield & Danckert, 2014).

High stimulation results in increased arousal: We saw increased EDA levels indicating increased arousal in the five and twenty seconds following the hazard indicating the critical nature of the hazard. Note that EDA levels were low *while* the hazard occurred, because EDA signals tend to be delayed slightly (Boucsein, 1992), and as such, the low levels of EDA are indicative of low arousal at the end of a long experiment, during which participants have converged towards a relaxed state. It is also known that, over time and towards the end of an experiment, people's biosignals tend to be less expressive due to habituation (Stern et al., 2001).

Similarly, we saw longer R-R intervals (i.e., slower heart rate and consequently lower arousal) *while* the hazard occurred. In the five and twenty seconds *following* the hazard, we saw shorter R-R intervals (i.e., faster heart rate) indicating elevated levels of arousal again. R-R responses tend to be more immediate than EDA. Although the R-R pattern mirrors the EDA pattern, there would have to be a different explanation than signal delay, e.g., directional fractionation and stimulus-response specificity. In this case, the decreased heart rate *during* the hazard might present a startle response similar to when we notice our wallet is missing (Stern et al., 2001).

5.3. Limitations

Inherent in every study are certain limitations that need to be considered when interpreting the results. Due to the composition of our study, the findings reflect the views of young male adults. We cannot generalise our findings to drivers of all ages and genders. However, young drivers are likely to be a major user group of safe-driving apps and are at greater risk for crashing (WHO, 2015). Furthermore, we expect to have identified the main effects, given we targeted the population most prone to feeling bored (Drory, 1982) and using phones in the car (Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005; White, Hyde, Walsh, & Watson, 2010), but more research is needed in this regard.

The heterogeneity of the studied sample with regard to driving experience limits the generalisability of the findings, considering driving behaviour is related to experience (McCartt, Shabanova, & Leaf, 2003). Likewise, prior experience with driving simulators, gaming, and previous iterations of the intervention might have affected participants' performance.

Due to non-parametric testing, which has less power to detect significance than parametric testing, quantitative results were often not statistically significant. A larger sample size would be required to detect significant results, however, our sample size was similar to related studies (Saifuzzaman et al., 2015; e.g., Savage et al., 2013/2) and sufficient to reveal trends in effect sizes.

The lack of significant differences of HRV could have been caused by the controlled laboratory environment. Specifically, the display system requires a darkened room for optimal visual presentation, and correspondingly, driving simulators are known to elicit lower arousal levels due to the reduction of ambient light (Philip et al., 2005). Moreover, the relatively short durations of the straight road segments may have not been long enough to induce a level of boredom that would have resulted in changes in HRV indices (Brookhuis & de Waard, 1993).

We saw some contradictory results for the subjective boredom intensity and arousal where some participants reported high boredom, but low arousal during the *control* condition. As a potential explanation for these mixed responses, participants' coping strategies such as the observed lane swerving or fidgeting, i.e., the natural regulation of attention, might have influenced the subjective experience and the way participants reported it.

At the beginning of this paper we talked about the risks of increased smartphone usage behind the wheel. To ensure a controlled experimental design, participants were not permitted to bring their personal smartphone into the vehicle. Future work should look into ways to compare the usage of habitual smartphone use versus dedicated boredom interventions. Furthermore, future work could investigate if participants are less likely to use their phones for other purposes if boredom interventions such as the *CoastMaster* app run on participants' phones.

6. Conclusion

We investigated the unique and safety-critical context of *driver boredom* in a simulator study. Digital technologies and gamification offer an untapped opportunity to re-engage drivers in the safe-driving task and to create safety benefits. This paper presented empirical data exploring the effects of this notion, contributing to a better understanding of boredom and engagement in the driving task.

The studied intervention contributed to a significant reduction of speed and significantly improved anticipatory driving. We also found effects of bringing the attention back to the primary driving task, evidenced in the driving behaviour data (improved lateral control) and physiological data (EDA showing higher arousal). We can further deduce that the intervention not only increased one's attention and arousal during the *intermittent* gamification challenges, but also in between. Such gamification stimuli may thus help to *sustain* one's attention and arousal throughout a trip. These insights mirror findings by Markey et al. (2014) whose experiments demonstrated that engagement in repetitive computer-based tasks can be increased through added challenge, performance feedback, and rewards. Our findings also upheld the predictions of the *opportunity-cost-model* by Kurzban et al. (2013), which projects that, in general, attentional resources are allocated to compelling tasks. Our study suggests that, in the driving context, such compelling tasks include gamified anticipatory or fuel-efficient driving.

These tactics of gamification can be built upon in future technology interventions. For example, future versions could include other aspects of the driving task, e.g., scanning the road environment. In semi-automated driving, where the human's role alternates between driving and monitoring, such gamification could offer safety benefits as well. Miller et al. (2015) found that people watching videos or reading were less drowsy than when overseeing the automated vehicle, indicating that additional stimuli can increase engagement in this context. Recently, Schroeter and Steinberger (2016) hypothesised that gamification and augmented reality may encourage voluntary attention and situational awareness in semi-automated driving. The results of this study support that argument, however, the effects of such interventions need to be carefully assessed for road safety.

We observed unsafe secondary activities to cope with driver boredom in the *control* condition such as as fidgeting, lane swerving, or eating, reaffirming the significance of the studied phenomenon. Conversely, EDA levels indicated a trend of increased physiological arousal through the intervention and possibly present a promising way to detect driver boredom. However, to what extent state boredom can be detected from such physiological data is still a question that requires further research. Contrarily, R-R intervals revealed no differences between the conditions, but future spectral analyses of HRV could provide more insights.

EDA may also present a promising option for future automotive user interfaces that collect driver state data. To that end, EDA sensors could be integrated into steering wheels and measure changes in the conductivity of the skin. Such configurations have previously been touched upon by Meschtscherjakov (2017) and Riener et al. (2017). Future work should explore further dimensions of driver states and boredom levels. For example, electroencephalography (EEG) has previously been used to generate indices of cognitive engagement (Hassib et al., 2017; Pope, Bogart, & Bartolome, 1995), which is a facet of task engagement (Fairclough et al., 2009/2009). Such additional contextual real-time data can be used to activate safety interventions. The more such contextual data is available, related to the driver, the vehicle, or the road environment, the more design opportunities for safety interventions are viable. Not only researchers, but also companies such as Seeing Machines[4] or Mobileye[5] have made advances towards detecting the state inside and outside of vehicles with a view of making driving safer.

The gamified condition led to slower reactions during a sudden hazard event in the middle of a coasting challenge. This could be attributed to the high cognitive workload demanded to deal with both situations simultaneously, and to the many short off-road glances suggesting visual attention was divided between the road and the smartphone application during challenges.

To further address visual distraction, future interventions should make more use of ambient interface design and, unless the vehicle is stopped, e.g., at a red light, visuals that are more complex than simple background colours should be carefully designed and evaluated. The screen positioning will always impact visual distraction too, and augmented reality (AR) head-up displays (HUDs) can greatly reduce this concern (Gabbard, Fitch, & Kim, 2014; Häuslschmid, Pfleging, & Butz, 2017) In our future work we are going to utilise AR HUDs as well as more sophisticated eye tracking tools to better understand this aspect of gamified driving. Multimodal output (e.g., ambient sound or haptic feedback) might be another option to present information to the driver, as suggested in recent work by Nykanen et al. (2016) and Christiansen et al. (2011). As such, our work opens up new directions for creating new interventions for safety-critical tasks.

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From Road Distraction to Safe Driving: Evaluating the Effects of Boredom and Gamification on Driving Behaviour, Physiological Arousal, and Subjective Experience

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Highlights

- Our driving simulator study addresses safety risks posed by boredom and low task engagement.
- A gamified intervention is studied as a means to increase engagement in the safe driving task.
- The intervention reduced speeding while promoting anticipatory driving.
- We infer that gamification may increase and sustain attention and arousal throughout a drive.