Designing Gamified Applications That Make Safe Driving More Engaging

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ABSTRACT
Low levels of engagement while driving can pose road safety risks, e.g., inattention during low traffic or routine trips. Interactive technologies that increase task engagement could therefore offer safety benefits, e.g., through performance feedback, increased challenge, and incentives. As a means to build upon these notions, we chose to explore gamification of the driving task. The research aim was to study how to design gamified applications that make safe driving more engaging. We present six design lenses which bring into focus considerations most relevant to creating engaging car applications. A user study enhanced our understanding of design requirements and revealed user personas to support the development of such applications. These lenses and personas informed two prototypes, which we evaluated in driving simulator studies. Our results indicate that the gamified conditions increased driver engagement and reduced driving speeds. As such, our work contributes towards the design of engaging applications that are both appropriate to the safety-critical driving context and compelling to users.

Author Keywords
Road safety; task engagement; gamification.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI).

INTRODUCTION
More than one million people die in car accidents every year [81]. Road crash statistics such as these offer evidence of the severe consequences resulting from human error, especially among young drivers [81]. Recently, there has been an increase in people accessing social media and apps while driving, as reported in Australia [10], Germany [79], and the US [49]. These kinds of distractions are often sought when engagement in the driving task is low, which may occur on familiar routes, in low traffic, or on long distance drives [70]. Similarly, the mundane nature of low-engagement driving situations may trigger equally dangerous behaviours, such as speeding [39,41,63,70]. However, drivers perform best and safest when they are adequately engaged in the driving task [85]. New car features offering semi-automated driving amplify the significance of this issue. Relinquishing manual control further decreases engagement, yet requires drivers to remain vigilant and take over control at any time [9].

CHI 2017, May 06 - 11, 2017, Denver, CO, USA

ACM 978-1-4503-4655-9/17/05…$15.00
DOI: http://dx.doi.org/10.1145/3025453.3025511

Figure 1: Study participants discussing driving experiences.

To limit disengagement and safety risks, Heslop et al. [26] and Schroeter et al. [62] proposed to develop and test interventions that encourage engagement in the driving task. As such, increasing the stimulus of the driving task itself can address safety risks caused by driver disengagement [62]. Studies by Markey et al. [38] revealed four effective strategies associated with heightened task engagement: increase challenge, offer performance feedback, provide social approval, and give incentives such as money rewards. Gamification (commonly defined as 'the use of game design elements in non-game contexts' [14]) puts these strategies to advantage. It has been shown to increase engagement in various settings [22,23,66]. Therefore, gamification provides a useful perspective from which to create and analyse engaging driving experiences.

The *research aim* of this work is to explore how to design gamified applications that make safe driving more engaging. Such apps could be implemented for, e.g., mobile devices or windscreen displays. Either of these approaches requires similar conceptual design considerations. These considerations are the focus of our paper.

To address this research aim, we present a user study, our iterative design process, and two prototype evaluations. Our study data reflect the diversity of user preferences, in particular regarding the presentation style of driving applications, which we discuss by way of three design personas. Key findings from our prototype evaluations include an increase in self-reported task engagement and a decrease in speeding violations. We address usability and safety considerations such as visual distraction in our design recommendations.

The contribution of our work is threefold. First, we offer six lenses through which to view the design of gamified driving applications. Second, we present new empirical data from a user study and ten design recommendations derived from it. Finally, through two prototype evaluations, we show how these lenses and recommendations can help to implement concrete applications that successfully increase task engagement. These contributions are timely as there is an increased attention on the use of apps in the car [51] and on keeping drivers in the loop in semi-automated vehicles [9].

BACKGROUND AND RELATED WORK

Engagement has been described as the quantity and quality of mental resources directed at a task [19,40,47]. Previous work has identified the positive impact of engagement (e.g., improved task performance, flow) as well as the negative consequences associated with a lack of engagement (e.g., boredom, mental retirement) [11,38,58,83]. Kurzban et al. [30] put forward a comprehensive theory, which describes that states like flow, boredom, and fatigue 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 result 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. To this end, we propose to tap into interactive technology.

In line with the opportunity-cost-model, Markey et al. [38] explored four determinants of value. As discussed, these are: increased challenge, performance feedback, social observation, and money rewards. All four strategies have been shown to relate to increased task engagement [38], feelings of competence [12], and a sense of progress [36]. Similarly, Orji and Moffatt [52] recently conducted a review of persuasive technology literature. It revealed that commonly used strategies for aiding users to adopt beneficial behaviours include tracking, monitoring, and performance feedback, as well as providing social support, rewards, and objectives. In terms of implementation, the authors identified mobile devices, social media, and games as most frequently used strategies.

Research on gamification has shown improvements in motivation and engagement [22,23,66]. Game elements such as progress and success feedback, goals, points, badges, levels, challenges, social feedback, leaderboards, avatars, and narrative, can all contribute to those engagement improvements, provided there is a good match between design and audience. We therefore propose to inform the design of engaging driving apps building upon gamification. However, in the safety-critical driving context, designing around game elements requires careful consideration, e.g., to avoid additional distractions [74].

Insurance companies and software developers have started to offer driving applications using gamification [14] and quantified-self [75] approaches. Gamified driving applications in particular have been explored as a means to influence eco-driving, driving safety, and navigation (see [15,78] for reviews). Such apps reward good driving with points and allow users to share their accomplishments with their social networks. Many apps offer insights after the drive and therefore do not influence driving behaviour in-situ. Other related applications provide feedback or stimuli during the drive, but without taking into account when it is safe to do so [e.g., 42,55]. As a consequence, they may become distractions themselves.

Irrespective of whether applications provide feedback in-situ or post-drive, gamified driving requires extensive user testing, as Diewald et al. [15] pointed out. However, there is a shortage of literature reporting both design recommendations and user studies. Steinberger et al. [74] proposed an approach for balancing safety and fun involving conceptual layers for designing driving gamification derived from game design cognition. Stevens et al. [3] established guidelines for in-vehicle information systems (IVIS), but little work has been done with regard to interactive applications. In terms of methodological approaches, Loehmann et al. [35] proposed storyboards and experience prototyping as tools to translate concepts into interactive products in the realm of automotive app design.

We build upon these related works and specifically explore the design of driving engagement through gamification. In particular, more work is needed to understand user requirements and contextual constraints in this safety-critical space – a gap this paper aims to address.

SIX DESIGN LENSES

To lay the basis for our work, we first present six lenses through which to view the design of gamified driving applications: *data, presentation, time, interface, social context,* and *road conditions*. Design lenses are analytical tools, which have been shown in HCI research to be useful for recognising design opportunities, formalising design criteria, and critiquing design work [48,87]. They therefore enhance the ways in which interactive technology can be developed and understood. Previous literature has shown the utility of design lenses, e.g., for informing sustainable HCI [54], crafting material interactions [82], evaluating player experience [60], and framing ludic engagement [48].

We identified the following six lenses *(L1 - L6)* from our own experience researching in-car user experiences. They do not represent a complete account, but rather a first articulation based on our engagement with the literature [e.g., 15,35,78] and our own research experience in the domain [e.g., 65,71,72]. They are a result of many cycles of concept development, design work, and user testing, and therefore the synthesis of an iterative process. The presented lenses were selected based on their relevance and usefulness in terms of balancing user experience design opportunities and road safety. Note that these lenses are not mutually exclusive, but rather complementary. Our study provides initial validation of a subset (four) of these design lenses as useful for our goal of engaging safe-driving. We believe that the lenses provide a structured foundation for designing gamified driving applications and offer practicable opportunities for researchers and practitioners who are interested in further exploring this space. Readers are invited to also consider the design lenses for a broader utility around user experience in the automotive domain.

L1: Data Lens – "What to Convey?"

There are three data streams relevant for providing feedback to drivers on their on-road behaviour [72].

Vehicle data includes location, direction, speed, acceleration, pedal pressure, fuel intake, etc. They can be gathered from smartphones, connected Bluetooth connectors for on-board diagnostics (OBD), or intelligent cars themselves [43]. The data can be exploited to facilitate feedback systems that go beyond the information displayed on the instrument cluster (speedometer, fuel gauge, etc.).

Road data includes specific traffic conditions, information such as following distance and road signs. These kind of data can be gathered through camera imagery, crowd-sourcing, map data, or smartphone sensors [1]. These data are required for context-awareness and can be used to gamify specific driving scenarios.

Driver data regarding the driver's mental and physiological conditions can be fed into applications. Biometrics, e.g., related to arousal, can contribute as an indicator for engagement in the driving task. For example, boredom while commuting would be reflected in low arousal levels and therefore suggest that adding gamification may be appropriate. Biometrics may furthermore feed into dynamic difficulty adjustment (DDA, [77]), e.g., to adapt gamified challenges to the current driver state so as to ensure optimal levels of engagement. Lastly, camera imagery and smartphone sensors can be used to detect facial expressions or characterise unsafe driving styles [86].

L2: Presentation Lens – "How to Convey?"

Generally, system output may, e.g., be visual, auditory, or tactile [53]. The following three parameters are an attempt at reflecting the variety of presentation styles, although they may not be applicable to every output modality.

Raw: A presentation of *raw* data is the most straightforward style, both to implement and for drivers to comprehend. For example, a digital speedometer displays numerical data as numbers. Graphs or sound may be used to convey raw data instantaneously or over time.

Abstract: Non-intrusive presentations could be achieved through *abstract* ambient visualisations that subtly convey information through colours, brightness, or sound. For example, ambient red colour may reflect speeding violations. This way, the level of granularity decreases for the benefit of reduced cognitive load.

Themed: Output on the other end of the presentation style spectrum can be playful, or *themed*. Themes and narratives can be added on top of gamification experiences or reward structures. They can amplify the intended effect of immersion and engagement if they resonate with users [74].

L3: Time Lens – "When to Convey?"

The activation and duration of applications may differ:

During – continuous: Applications displaying information *during* trips may offer them *continuously* throughout the entire drive. They could be switched on prior to commencing a trip and act as ambient feedback systems that continuously emit minimal audible cues or display data in real-time, similar to speedometers or fitness trackers.

During – event-triggered: Driving games can be activated by elements in the road environment. For example, a speed sign or a set of traffic lights could activate a gamified driving task. These interventions could add additional engagement on top of a continuous feedback loop, similar to mini games within a videogame.

Before/After: Driving challenges or feedback can furthermore be displayed *before* or *after* drives when the vehicle is not in motion. For example, a challenge might be suggested at the beginning of the drive ("try to use less than X amount of fuel while driving to work today") and take place mainly in the driver's head during the trip. Detailed feedback could be provided after a journey, e.g., performance indicators accumulated throughout the entire drive and information that cannot be displayed in a subtle, non-intrusive manner. As part of post-drive feedback, it is also possible to display leader boards or similar statistics.

L4: Interface Lens – "Where to Convey?"

Designing new interfaces to engage drivers poses the question of which technology platform to use. Relevant data streams and presentations may rely on different technologies for implementation, such as:

Car as a platform: Integrated dashboard or head-up display (HUD) applications, e.g., using Apple CarPlay and Android Auto, make smartphone applications accessible to drivers. Opportunities for novel in-vehicle applications are facilitated by recent automobile technology developments, including those with semi-automated driving features. The car and driving environment can be viewed as a development platform on which safety interventions can thrive (though within the context of due consideration of emerging ethical and safety issues [61,84]).

Consumer electronics: Smartphones, smart watches, physical activity trackers, and dashboard cameras have entered the driving space. These devices have essentially become automotive user interfaces, even though they were never designed as such [51]. Their increasingly sophisticated sensing, networking, and output capabilities provide an untapped opportunity to develop driving apps. We propose to leverage such devices available to drivers today for immediate safety and user experience benefits.

L5: Social Context Lens – "With Whom?"
Interactions with other road users and passengers present another lens through which to view the gamified driving.

Other road users include drivers of nearby vehicles as well as pedestrians and cyclists. Besides these co-located road users, one can also take into account drivers that have shared the same road at a different point in time, e.g., ten minutes earlier or every morning as part of commuting. Applications may target other road users to reward achievements [64], allow social expression [57], enable serendipitous encounters [76], or facilitate shared road trip experiences [29]. Users of driving games may compete with each other and compare their progress on leaderboards.

Passengers, on the other hand, can be a source of social entertainment themselves. Novel in-car interfaces can support such interactions. For example, they may allow for collaborative navigation input or information sharing among passengers [45].

L6: Road Conditions Lens – "When Is It Appropriate?"
Apps should be created with road conditions in mind, e.g.:

Highway and suburban driving are often associated with commuting, low traffic, or constant speeds. The latter are common antecedents of low levels of engagement [70] and should therefore be at the focus of gamified driving.

Inner-city driving is often related to congestion, low visibility, and fear of being caught speeding and, as such, often associated with high levels of vigilance and stress [70]. Added stimuli in these conditions may cause distractions or incentivise unsafe behaviour.

Currently, developers need to rely on drivers to activate applications within appropriate conditions. In the near future, the increased contextual awareness of connected and semi-automated cars will provide a more fine-grained evaluation of appropriateness and greater scope for exploring automated interventions.

USER STUDY
The presented lenses allow designers to understand opportunities for gamified driving more broadly. As a next step, we aimed to derive specific design recommendations and user preferences for future prototypes. To this end, we conducted a study involving potential users early on in the design process, inspired by human-centred design [27] as well as experience design [24]. We were then able to look at the study data through appropriate lenses.

Storyboards
In preparation for the user study, we created five storyboards to brainstorm initial gamified driving concepts and to solicit feedback from study participants, as suggested for early design exploration in general [8] and for designing car applications more specifically [35]. Our concepts were inspired by a review of driving-related video games [73], and we followed a design approach for balancing fun and safety in gamified driving [74]. Each storyboard was built around a typical driving situation (e.g., red light or new speed limit), rather than a specific technology.

BrakeMaster gamifies approaches to red lights. Ideally, the driver will slow down gradually instead of braking abruptly. When the car comes to a halt, the game will display a playful assessment of the braking performance.

CoastMaster encourages drivers to smoothly and timely slow down to a new speed limit. The goal is to pass a road sign at the speed it displays and awards extra points for coasting and avoiding harsh braking.

Mirror Music reminds drivers to periodically check their rear-view and side mirrors. If the driver neglects to check the mirrors, music played through the car stereo will decrease in volume to gently remind the driver to glance at the mirrors. Conceptually, this is about providing awareness and feedback on how often drivers check their mirrors.

Zombie Cloud is a concept to help drivers avoid tailgating. It signals a minimum safe distance to the frontward car by virtually augmenting the driving environment. Virtual toxic clouds surround nearby vehicles and signal that a safe distance should be maintained.

Coin Collector encourages drivers to keep to their lane. Virtually displayed coins, as known from games such as Super Mario, suggest an ideal driving path. They can only be collected if the vehicle stays within bounds. To prevent speeding or tailgating, coins will disappear as soon as the driver is going too fast or too close to the frontward vehicle.

Participants
Overall, 24 drivers participated in the study (age M=20.25, SD=1.82; driving experience M=2.88 years, SD=1.36; all male). We deliberately recruited young male adults, since research confirmed that they are particularly susceptible to crashing [81], risky driving [80], phone distractions [88], and feeling disengaged [16]. The pre-existing interest in digital games prevalent in this group [6] made exploring gamification particularly promising. We recruited participants on our university campus and at car meet-ups. Data saturation [5] determined our sample size, i.e., data collection concluded when minimal new information was obtained from further sessions.

Procedure
Each of the study sessions consisted of two participants who knew each other. The rationale was to provide a comfortable setting for participants in the two-part study.

The first part took place in a driving simulator, where a real car is positioned in front of a projection screen. We played back 20 minutes of real-world video footage of typical inner-city, highway, and suburban driving. This safe setup has been proven to be effective in immersing participants in the driving context [69]. Figure 1 shows two participants in the simulator vehicle, where we encouraged them to chat with each other while watching the video footage, borrowing from think-aloud techniques [50].

The second part of the study continued with interviews in a nearby room, which lasted approx. 30-40 minutes. There, we presented the storyboards to induce participant feedback (Figure 2), a technique proposed by Greenberg et al. [21] and previously used in designing in-car experiences [35].

Audio recordings were made of all sessions and later transcribed verbatim. The transcribed responses were analysed independently by two researchers based on thematic coding methods, as proposed by Miles et al. [46].

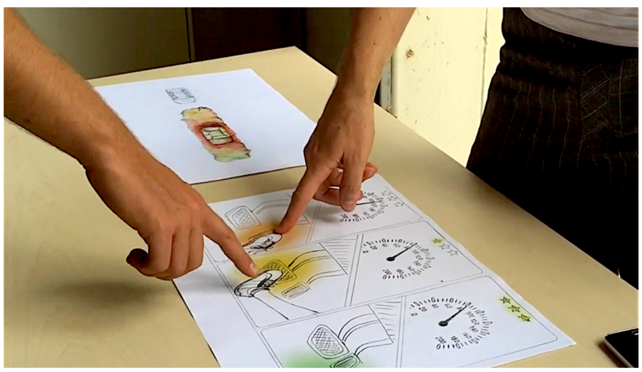

Figure 2: Study participants discussing storyboards.

RESULTS & DESIGN RECOMMENDATIONS

Our understanding of user requirements was enhanced by viewing the interview data through appropriate design lenses. This richer understanding allowed us to formulate ten design recommendations *(Recommendations 1 - 10)*.

Engaged Driving (Data Lens & Road Conditions Lens)

The interview data revealed participants' desire to alleviate boredom while driving as well as coping strategies to make driving more engaging. We found that engagement is particularly associated with economic and anticipatory driving. Participants said they would typically focus on fuel consumption if they had to pay for petrol themselves (rather than their company or parents) or if they were low on fuel (P17, P18, P15, P14). In these situations, they would be more aware of their driving style and attempt to *"get the max amount [of kilometres per litre] as possible"* (P14). Others would exploit gaps to go past other cars (P24) and try to get ahead of slow traffic (P17). Zipping in and out of lanes was described as *"a bit fun," "more entertaining,"* and *"making you feel you're achieving something"* (P21, P19, P24). P13 and P14 reported purposely driving over lane markers: *"my car is really stiff, I feel every bump so I just try and hit every cat eye."* Five participants praised anticipatory concepts such as *CoastMaster*, which requires drivers to look ahead and take road characteristics into account. Finally, it was pointed out that speeding itself *"is kind of a reward, it's more fun to drive faster"* (P8). These responses underpin a demand for engagement we aim to meet with gamifying simple driving tasks.

Recommendation 1 – Anticipatory Driving: Applications aimed at increased task engagement should build upon the notions of economic and anticipatory driving.

In-Car Setting (Social Context Lens)

Three participants indicated feeling engaged when they could interact with others (P8, P9, P14). For example, P8 reported enjoying talking to other passengers in the car or to someone on his phone. Three participants (P13, P14, P19) reported feeling more engaged when they could show off. P19, e.g., enjoys *"hearing the sound of your car when you accelerate"* and P14 reportedly tries to make his car *"sound louder than everyone else's."*

Recommendation 2 – Use Competition: Applications should build upon the notions of competition and social approval.

Reward Structure (Presentation Lens)

Strikingly, participants reported they would be inclined to aim for the lowest score rather than the encouraged safe performance. As claimed by P24 (also P23, P16), he would *"pride [himself] on being zero stars at all times."* Similarly, a participant addressed the choice of a zombie theme in the tailgating scenario: *"Zombies would encourage me to drive closer to the car in front of me"* (P8). As a design implication, we recommend displaying no rewards or feedback at all for selected relevant use cases. In *CoastMaster*, e.g., if users exceed the speed limit, we suggest displaying 'invalid user input.' This may reduce users' temptation to explore the game boundaries, and therefore keep them from undesired and unsafe behaviours.

Rewards may be perceived differently in another way. In the *Mirror Music* storyboard, for instance, the music playback would be kept at the same volume only if drivers checked their mirrors frequently. Two participants signalled they would not use an app that turns down their music as *"listening to music is the best part of driving"* (P4) and *"something like this would annoy me to tears"* (P9).

Recommendation 3 – Allow Customisation of System Feedback: Apps should be customisable by the driver (e.g., choosing whether the music in the car is affected by their performance). This helps to avoid that feedback is perceived as punishment.

Challenge and Progress (Data & Road Conditions Lens)

Participants expected an adequate level of challenge from driving for it to be regarded as fun. Participants suggested that *"a game should only challenge driving activities that you aren't good at already"* (P7, also P8, P21). P15 admitted being *"pretty horrible at braking,"* and said an app aimed at smooth braking would be a fun learning activity. Four participants likewise pointed out they liked the educational aspect of concepts that encourage smooth driving (P16, P24, P23, P22). Three participants revealed that apps might succumb to the novelty effect (P1, P7, P16). P16 proposed to offer various levels of difficulty in order to maintain a sense of challenge and progress.

Recommendation 4 – Improve Driving Skills: Exploiting people's interest in skill progression is a promising pathway to explore for gamified driving (studies on motivation, games, and gamification support this notion [2,13]). Maintaining a sense of challenge can be achieved by offering different gaming themes, various levels of difficulty, competing with other users, or new driving challenges. Driving challenges may be designed around smooth driving to maximise passenger comfort, around efficient driving to address range anxiety in electric vehicles, to increase situational awareness in semi-automated driving, or to keep skilling the driver as vehicle automation may have deskilling effects. Such challenges may be complemented by enticing new user interface technologies, e.g., augmented reality using 3D head-up displays or windscreen displays.

Themes (Presentation Lens)

Our analysis revealed that *presentation* was not only by far most discussed (119 of 227 interview statements), but also showed the greatest disagreement between positive (25) and negative statements (36). Regarding the negative statements (dislike, disagree, etc.), we must note that we had initially designed the storyboards in a playful way making use of rich themes such as zombies (see *Storyboards* section). Our original rationale behind this presentation style assumed that playful themes would be compelling to users, based on literature which suggested that themes and narratives increased the likelihood of engagement [66].

We found that there was no consensus about which presentation style was favoured most (*raw, abstract,* or *themed*). Furthermore, even within *themes*, participants' opinions strongly diverged. For example, P6 said, *"I'm a big zombie fan so I think that'd be good fun,"* while P23 revealed he was not a *"zombie person."* It is unlikely that any one theme will appeal to everyone.

Recommendation 5 – Provide Users with Choices: In terms of design, users need to be given driving application choices, just like on app stores, or in media consumption in general, because there are likely no 'one size fits all' solutions. (Note that within research projects of limited scope it may not be possible to provide a rich selection of different apps).

Recommendation 6 – Avoid Testing Themes Early: In terms of testing, we recommend to explore themes at late stages in the process. This is because themes can easily dilute the results if there is a mismatch between user preference and theme. Note that delaying theme considerations does not preclude identifying game mechanics early on.

Recommendation 7 – Know Preferences When Testing: When testing themes, we recommend to assess user preferences to establish potential matches and mismatches. A game mechanic can be applied in tandem with varying themes, so customising themes may be an option.

We further unpack the implications of highly varied user preferences by presenting different personas, for which we formulate specific design recommendations.

Design Personas

Viewing the interview data through a *presentation* lens revealed differences and patterns in user preferences. Design personas are useful to reflect such differences and patterns [56]. They are a common tool in interaction design to illustrate different user types that might use a product in a similar way, and serve as a tool to conceptualise and communicate design concepts [33].

We propose three design personas representing three different preference clusters concerning *presentation* styles, which we argue are most critical in designing compelling apps: *Motorhead Max*, *Imaginative Ian*, and *Competitive Cody*. These personas are not necessarily mutually exclusive, but serve to facilitate the design process.

Motorhead Max

Motorhead Max is someone who identifies as car-savvy. This persona typifies drivers who would prefer to receive as much data as possible about their vehicle and their driving. Their preferred presentation style is raw data such as numbers or simple graphs without elaborate styling. They feel competent in interpreting these raw data and draw pleasure from monitoring, optimising, and comparing data. *Motorhead Max* represents quantified-self enthusiasts who have an interest in personal informatics such as physical activity tracking. Providing real-time performance feedback is one promising strategy to increase task engagement [38]. *Motorhead Max* responds to this strategy.

Evidence: Four participants who identified as car enthusiasts (P11, P17, P18, P20) indicated they would prefer raw data and simple visual representations. For example, P17 said he was *"more looking for the raw data than anything."* Two participants pointed out their interest in technology and stated *"the more information about my car and my driving the better"* (P14, also P13). It appears that those drivers would prefer *"a more technical evaluation of your driving"* (P20) rather than playing a driving game. Other participants added that driving feedback needed to be performance-related (P15) and accurate (P22). This accuracy would allow users to improve over time. In order to maximise their fuel efficiency, they would *"check their gears and revs"* (P9) and avoid braking if not necessary (P21). One participant recollected *"making a bit of a gamble of trying to get to a petrol station"* (P24), which resulted in him feeling very attentive about his driving style. Another participant said that he would use instantaneous fuel economy displays *"as a bit of a game to* *see how high [he] could get it up, for no particular reason apart from self-satisfaction"* (P18). Lastly, a participant pointed out that, as an added benefit, being mindful about fuel consumption would *"also prevent [him] from speeding"* (P23).

Recommendation 8 for Motorhead Max – Provide Vehicle Data: A driving app would have to be able to gather real-time driving data and display them to cater to *Motorhead Max's* interest. Vehicle data is most important to this persona, as is data accuracy. Inspiration regarding the presentation of these data may be drawn from IVIS as well as quantified-self apps.

Imaginative Ian

Imaginative Ian is someone who is attentive about their driving style as well as their surroundings. This persona represents drivers who make use of their spatial and situational awareness not only to respond to their environment, but also to anticipate what may lie ahead. If conditions allow, they may use their awareness and imagination to come up with ways to make their driving more challenging or satisfying for themselves. For example, they try to optimise their smooth driving to maximise passenger comfort. In terms of preferred presentation style, they expect simple and abstract information where the level of detail from plain raw data has been reduced. Their main interest lies in receiving just enough input that would allow them to imagine their own safe-driving games. Otherwise, they would focus on their surroundings and prefer for the data to disappear. Making the task at hand more challenging is one promising strategy to increase task engagement [38]. *Imaginative Ian* responds to this strategy.

Evidence: These characteristics are informed by participants who said they had already created games in their everyday drives. For example, P9 would often coast down to red lights when he anticipated they were about to turn green. Participants reported they would read their speed or fuel economy, compare it to previous drives or other drivers, and try to improve. Continuous challenges or continuous feedback loops were favoured by three participants (P21, P9, P8) and described as *"more relevant and engaging for longer"* (P21). These participants responded well to anticipatory storyboard concepts such as *CoastMaster*, which require drivers to look ahead (P23, P14, P24, P13, P22). Three participants mentioned they would *"start experimenting with the app just to learn how it works and then stop"* (P4, also P9, P7). More *"subtle background information,"* however, was considered unlikely to become less interesting (P9, P10).

Recommendation 9 for Imaginative Ian – Design Non-Intrusive Apps: To increase user acceptance for *Imaginative Ian*, driving apps should be non-intrusive. User interfaces need to be carefully designed for this persona to avoid visual distractions, e.g., by making use of ambient design. Furthermore, applications may display nothing at all and just emit minimal audible cues. For example, a challenge might be suggested at the beginning of the drive ("try to use less than X amount of fuel to work today") and take place mainly in the driver's head during the trip.

Competitive Cody

Competitive Cody portraits users who enjoy games that incorporate rewards and competition among users. While they may not be enthusiastic about cars, they respond to the playful and social elements provided by games. They personify users who check their position on leaderboards and challenge their friends. As they draw pleasure from the game's artwork, which amplifies the desired effect on immersion and engagement, they prefer *themed* presentations. Providing rewards and social approval are promising strategies to increase task engagement [38]. *Competitive Cody* responds to these strategies.

Evidence: This persona has been drawn from interview data in which seven participants indicated they would be inclined to perform better if there was an opportunity to receive real-world rewards, e.g., discounts at service stations (P7, P8, P9, P10, P16, P14, P13). It also personifies participants who favoured playful themes over data, such as P6: *"I'm a big zombie fan so I think that'd be good fun."* Furthermore, P8 and P16 suggested to compare their own scores with other users in the area or compete with friends. Themed performance feedback was often desired *post-drive*. P11, e.g., suggested to derive scores and statistics such as an average performance for each trip.

Recommendation 10 for Competitive Cody – Consider Pre-Drive and Post-Drive Contents: Driving games may provide an engaging stimulus to otherwise boring drives, which gives *Competitive Cody* something to do and look forward to. Designers can avoid challenges related to visual distraction through pre-drive and post-drive app contents (when the vehicle is not in motion) while still addressing *Competitive Cody's* desires in terms of artwork and competition. If the game is activated and played *during* drives, designers could resort to immersive augmented reality technologies such as 3D head-up displays with world-fixed graphics [20].

PROTOTYPE EVALUATIONS

Equipped with these insights, we implemented two prototypes, *BrakeMaster* and *CoastMaster*. Considering the ubiquity of smartphones in everyday life, including the driving context [51], we presented the prototypes as smartphone apps to our participants. Note that, conceptually, nothing speaks against implementing them as dashboard or head-up display applications. We evaluated both applications with users to explore the feasibility and usability of gamified driving. We also collected data regarding task engagement. The results are promising.

BrakeMaster

We created a first prototype to learn and iterate quickly, as proposed by Buxton et al. [8]. We chose to first prototype *BrakeMaster*, which seemed easiest in terms of development scope. It does not require to display any visuals while the vehicle is in motion, and therefore we did not have to consider visual distraction in the design at this point. This prototype offers a technical representation of the driving performance rather than a playful theme. This change to the original storyboard addresses *Motorhead Max's* interest in accessing raw data *(Recommendation 8)* and avoids a potential mismatch of user preference and implemented theme *(Recommendation 6)*.

We implemented *BrakeMaster* as an Android application that connects to on-board diagnostics (OBD). It shows a black screen while driving. Upon approaching a red light, an audio instruction signals the beginning of a new challenge, inviting the driver to match a deceleration curve instead of braking abruptly. When the car has come to a halt, the app will display an assessment of the braking performance visually as a graph (Figure 3) and via audio feedback before the vehicle is set into motion again *(Recommendation 4)*. We suggest to base the exact nature of desired braking patterns on transportation literature and to be context-dependent. (More on gathering real-time driving data from mobile and wearable devices in [72].)

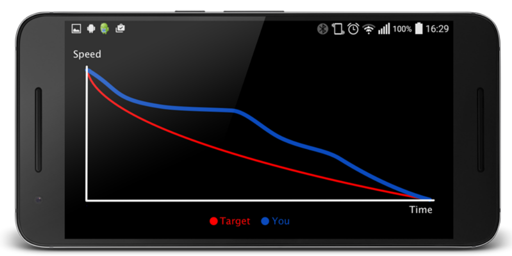

Figure 3. Prototype implementation of *BrakeMaster*.

Evaluation Study

We conducted a driving simulator study using the prototype to learn about its usability and user experience. Given the explorative nature of our rapid prototyping approach, the only participant selection criterion for this first evaluation was the possession of a valid driver's license. Overall, ten people (*M*=29, *SD*=4.42) participated in the study. We designed the evaluation as eight minutes of suburban driving. Participants encountered nine signalled intersections and five red lights, which triggered *Brake-Master* challenges. A smartphone running *BrakeMaster* was placed behind the steering wheel where dashboard displays are usually positioned. In terms of data collection, we administered the System Usability Scale (SUS), which provides a metric for overall product usability and can be used on small sample sizes with reliable results [7]. Semi-structured interviews were conducted with five participants.

Evaluation Results

The mean SUS score for *BrakeMaster* was *M*=78.5 (*SD*=16.55), on a scale from 0 (worst) 100 (best). According to literature [4,32], these data suggest good and above average usability and indicate that the game objective was well understood and desirable enough to be pursued. The interviews support these data. P1 felt *"happy to engage with the challenge and to get positive results,"* and he reported feeling *"a small sense of accomplishment"* when receiving positive feedback. P6 felt that *BrakeMaster* targets a familiar issue and said, *"highway driving or typically monotonous driving is just repetitive, but you have to focus on it."* Furthermore, P6, being *"fairly competitive,"* said, *"I like the idea of playing the game,"* although in the long run, the game should change from time to time to remain interesting. P7 said that the visual feedback helped him improve his driving performance. Considering the motivation behind the app, these results are promising. We therefore decided to continue our path with a second prototype iteration.

CoastMaster

Equipped with considerations from the first evaluation, we created a second prototype. This time, we explored a different scenario, i.e., approaching speed limits with *CoastMaster*. By gamifying a different driving situation, we address the participants' desire for more variation *(Recommendation 5)*. *CoastMaster* targets transitions to new speed limits. Since these transitions occur while the vehicle is in motion, and given driving is a highly visual task [67], complexity is added to the design. We therefore focussed on viewing this design iteration through the *presentation lens (L3)*, which included investigating usability and visual distraction.

Research suggests that eye glances greater than two seconds significantly increase crash risk and should therefore be minimised [28]. The literature around ambient interface design provided a useful perspective on this requirement. In applying ambient interface design, we also responded to *Imaginative Ian's* preference of simple, abstract visualisation *(Recommendations 6 and 9)*. This persona is important to consider when prototyping *CoastMaster*, which particularly targets anticipatory drivers *(Recommendation 1)*. Our designs were informed by heuristics for ambient displays [37] and IVIS design guidelines [3]. In the end, we independently arrived at a design similar to the digital speedometer proposed by Smith et al. [68], which may suggest a level of maturity in the design of this particular use case. (More information on the design process can be found in [71].)

CoastMaster serves as an ambient speedometer and gamifies transitions to new speed limits. Similar to related work by Ecker et al. [17], it encourages users to coast down to new speed limits without unnecessary pedal usage. The game objectives are: firstly, to stay within the speed limit, and, secondly, to do so with limited pedal usage even when the speed limit is changing. Upon approaching a lower speed limit, a visual icon and an audio cue signal the beginning of a challenge. 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. During the coast down phase, a vertical bar will move across the screen representing the remaining distance to the approaching speed sign (Figure

4). Along this vertical bar, a trace visualises pedal use, i.e., using no pedal (blue), using the accelerator pedal (yellow), and using the brake pedal (red). Once the car passes the speed sign, the app will display an assessment of the gameplay performance, which is also conveyed through an audio cue. Red background colour signifies exceeding the new speed limit (failed challenge), and a reference line allows users to assess their own smooth driving performance *(Recommendation 7)*. *CoastMaster* was implemented as a web app using HTML5 and JavaScript.

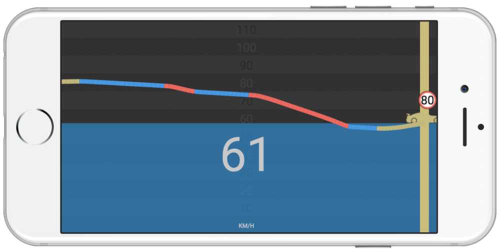

Figure 4. Prototype implementation of *CoastMaster*.

Evaluation Study

In a driving simulator study (*N*=24), we compared a gamified and a non-gamified interface with regards to user experience, driving performance, and visual distraction. 19 male drivers aged between 18 and 25 (*M*=22, *SD*=2.94) were recruited in line with our research program focus. The remaining five participants were road safety researchers (*M*=30.8*, SD*=4.76) who would provide feedback from their perspective. We designed the evaluation as a within-subjects, repeated measures experiment with two counterbalanced conditions across participants, *control* and *game*, and ten minutes of driving per condition. During each condition, participants would encounter 13 speed limit signs that resulted in eight slowdown transitions, i.e., eight *CoastMaster* challenges in the *game* condition, which each lasted approx. ten seconds. In terms of data collection, participants completed a disengagement questionnaire (subscale of MSBS [18]), which was previously used in task engagement studies [38]. Furthermore, the AttrakDiff 2 Questionnaire [25], a widely used instrument in HCI and AutoUI research to quantify hedonic and pragmatic qualities, was administered. To investigate visual distraction, we measured long (>2s) eye glances away from the driving environment with the ASL Mobile Eye-XG eye tracker. We also recorded driving speed. Lastly, we recorded driving speed and conducted semi-structured interviews with all 24 participants.

Evaluation Results

Disengagement is significantly higher in *control* (*M*=3.08, *SD*=0.14) compared to *game* (*M*=2.85, *SD*=0.07), as a paired t-test revealed ($t(24)=-1.88$, $p<.05$).

The AttrakDiff data suggest an increase in hedonic quality (HQ) through the gamified component (0.69 in *game* vs. -0.01 in *control*), on a scale from -3 (worst) to 3 (best). A closer look at HQ demonstrates a significantly higher value in HQ-*Stimulation* (*Z*=-2.9143, *p*=.004) in *game* (0.87) compared to *control* (-0.21). A Shapiro-Wilk normality test revealed that not all of the measurements are normally distributed. Therefore, a Wilcoxon signed-rank test was used to calculate significance. In the interviews, participants self-reported having more fun, feeling more challenged, and feeling less bored through the gamified component. Most participants agreed that the game component added *"that bit extra in it"* (P20) that made the drive more fun and challenging. P13 and P19 felt *"satisfied"* when their performance overlapped with the reference line illustrating the desired performance. Other participants felt *"frustrated and betrayed"* (P6) when they failed to achieve the desired performance.

The number of long (>2s) eye glances was significantly higher (*Z*=-2.87, *p*=.004) in the *game* condition (*M*=12.12, *SD*=9.31) compared to *control* (*M*=7.82, *SD*=8.40). The fact that participants glance at the screen more often in the *game* condition suggests visual distraction. The AttrakDiff data provides some insight into the cause of this: The pragmatic quality (PQ), i.e., the usability, is significantly (*Z*=-2.42, *p*=.016) lower in *game* (1.32) compared to *control* (1.46). This indicates that the ambient speedometer by itself was perceived and understood more easily than the version with the added game component. In the interviews, 22 participants pointed out they could see the speedometer information in their periphery.

We calculated the mean driving speed throughout the entire drive for each participant in both conditions (similar to Meschtscherjakov et. al [44] who studied an ambient LED system to support speed control). Our results show a significant (*Z*=-2.14, *p*=.032) mean speed drop of 0.79 km/h in *game* (*M*=62.1 km/h, *SD*=3.14) compared to *control* (speed *M*=62.89 km/h, *SD*=3.1). We then isolated the road segments that included coasting challenges, i.e., 250 meters before a speed limit sign. These segments reveal a significant (*Z*=-8.01, *p*<.001) lower mean driving speed in the *game* condition by 4.19 km/h (*M*=63.02 km/h, *SD*=4.89 in *game* vs. *M*=67.20 km/h, *SD*=4.22 in *control*). This result is due to earlier and smoother deceleration.

In summary, disengagement, driving speed, and interview data suggest increased task engagement through the gamified component.

DISCUSSION

We now discuss our work with respect to our research aim of exploring the design of gamified driving applications. Returning to the motivation of our work, we also discuss our results in light of task engagement and road safety.

Implications for Design

This paper presented six design lenses *(L1 - L6)* through which to view the design of gamified driving applications. We have shown, by applying four of them in our presented work, how they can be useful in various stages of the design process. As a result, we provided ten concrete design recommendations *(Recommendations 1 - 10)*, which researchers and practitioners can apply and extend in their own work. Similarly, our three presented user personas can serve as tools when designing driving related applications, and can be expanded accordingly.

Through the interviews, we identified that many drivers come up with their own gameful experiences. This relates to the concept of bottom-up gamification [31]. Rather than providing gamefulness from top-down, some users prefer the autonomy in imagining their own games around real-time performance feedback or other data. Lessel et al. [31] have shown that this approach is appealing for some user groups, and our data confirm this, which is also reflected in the *Imaginative Ian* persona.

Drawing attention to semi-automated driving, cars are gradually evolving through several levels of partial, conditional, and high automation [59]. One can expect some form of manual control in various geographies for at least the next two decades [34], which emphasises the ongoing need for task engagement and corroborates the relevance of this work. Our lenses, recommendations, and personas offer tools for exploring ways to keep drivers in the loop, e.g., to respond to handover requests.

Task Engagement and Road Safety

Our prototype evaluations have shown promising results in terms of increasing task engagement. These results upheld the predictions of the *opportunity-cost-model* by Kurzban et al. [30], which projects that, in general, attentional resources are allocated to compelling (or valuable) tasks. Our work indicates that this model holds true in the driving context. Our results also mirror findings by Markey et al. [38] whose experiments demonstrated that engagement can be increased through added challenge and providing real-time performance feedback. Our work suggests that these strategies can encourage engagement in the driving task as well. We acknowledge that our engagement data was self-reported by participants. More work is needed to collect objective data, e.g., through physiological and driving performance measures.

In terms of road safety, *CoastMaster* successfully encouraged safe driving as we have observed significantly lower driving speed as well as earlier and smoother deceleration. The mean driving speed reduction through the gamified component is comparable with related ambient display studies [44]. We have furthermore observed that visual distraction *during* challenges is too high. As pointed out [44], there is a trade-off between providing ambient information and driver distraction. This aspect needs to be addressed through further design iterations. A potential avenue to explore is ambient sound, which some participants said they might prefer, and how it might complement ambient visuals. Finally, our proposed personas and prototypes may be useful to more accurately model the impact on driving behaviour and, as such, better predict road safety benefits.

Limitations and Future Work

Although the study was carefully designed and carried out, we are aware of some limitations. We acknowledge that neither the list of design lenses nor the personas provided may be complete. Due to the composition of our initial user study, the findings reflect the views of young male adults. We cannot generalise our findings to drivers of all ages and genders. However, we believe young drivers to be a major potential user group of safe-driving apps. Furthermore, we expect to have identified the main design requirements, given we targeted the population most prone to feeling disengaged [16] and using phones in the car [88], but more research is needed in this regard. Lastly, we needed to remind participants to assume a safe implementation of the low-fidelity storyboards. We are aware this was a difficult task for participants and, more broadly, acknowledge this a common challenge in low-fidelity prototyping [21].

More work is needed to test applications like those proposed in this paper in order to evaluate safety-critical aspects such as lateral lane control, reaction times, distraction, and hazard perception. Future work should also investigate gamified driving with regards to flow [11] and boredom [30]. To this end, our proposed personas may be useful in recruiting the right study participants. In our future work we will sample participants that fit into the persona for whom future prototypes will be designed. Finally, more research is required to design not only for other demographics, but also for other safety-critical contexts, e.g., operating machinery in mining or manufacturing, air traffic control, or truck driving. To our knowledge and according to a recent literature review by Seaborn and Fels [66], gamification has not been studied in these domains.

CONCLUSION

Gamified driving offers an untapped opportunity to re-engage drivers in the safe-driving task and to create novel driving experiences. This paper presented empirical studies to investigate the design of gamified applications that make driving more engaging. We discussed how the six design lenses *data, presentation, time, interface, social context,* and *road conditions* are useful to bring into focus user needs and contextual requirements throughout the entire design process. Applying the lenses informed ten concrete design recommendations, e.g., around anticipatory driving and skill progression. Three presented user personas alleviate challenges faced by designers who develop driving applications for users with distinct preferences. As our prototype evaluations indicated, these tools can support the design of applications that make drivers feel more engaged in the driving task and be less tempted to take risks. As such, our contributions pave the way to developing new safety interventions for researchers and practitioners who aim to curb the road toll.

ACKNOWLEDGEMENTS

This work was supported under the Australian Research Council's Discovery Early Career Researcher Award (ARC DECRA) funding scheme (project number DE140101542).

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