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Gamification and sensory stimuli in eco-driving research: A field experiment to reduce energy consumption in electric vehicles

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ABSTRACT

Gamification can create meaningful engagement for users and foster desired behaviors. In gamification research, however, the importance of sensory stimuli often has been overlooked. We examine and discuss how the variation of visual and auditory stimuli in gamified driving influences users' eco-driving behavior. We conducted a field experiment where eco-driving is the field of application and energy consumption the dependent variable. Participants performed test drives with a battery electric car whilst using a mobile application that supports participants to drive more eco-friendly. We varied the extent to which the application employs visual and auditory stimuli. Our results of an analysis of covariance (ANCOVA) and multivariate analysis of variance (MANOVA) show that, depending on the stimuli configuration, participants expose different levels of energy consumption and experience different levels of enjoyment as well as different intentions to actually use this mobile application. More specifically, through the ANCOVA, we find significant differences of the energy consumption between the control group, who drove without the gamified application, and the visual-auditory group, as well as between the visual-only and the visual-auditory group, both at a p-value of 0.02. Further, the MANOVA reveals significant differences between the visual-only and visual-auditory group at a p-value of 0.01 for both perceived enjoyment and intention to use. Due to the significant impact of the varied sensory stimuli on the outcomes, we conclude that the choice and design of sensory stimuli play an increasingly important role in real-time gamification in safety critical situations.

1. Introduction

The benefits of gaming are increasingly recognized as an asset to foster desired behaviors, which is why products and services that have not usually been associated with games, are becoming more and more *gamified*, meaning that game design elements such as leaderboards, challenges or badges are introduced into non-game application contexts (Deterding, Dixon, Khaled, & Nacke, 2011; Hamari & Koivisto, 2015; Putz, Hofbauer, & Treiblmaier, 2020; Suh, Cheung, Ahuja, & Wagner, 2017). Yet, most gamified applications are predicted to fail to meet corporate objectives, primarily due to poor design (Burke, 2013). This challenge has led to an interest in research that examines the design and evaluation of gamification (Morschheuser, Hassan, Werder, & Hamari, 2018; Mulcahy, Russell-Bennett, & Iacobucci, 2020; Rapp, 2017).

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In the growing stream of research on gamification design and evaluation, a variety of gamification elements such as leaderboards and badges have been in the focus (see, e.g., Enríquez, Troyano, & Romero-Moreno, 2019; Hamari, 2017). However, knowledge on gamification design is still incomplete, in particular the importance of sensory stimuli has played an underrated role so far. Sensory stimuli are detectable signals from inner or outer environments that can be received and interpreted by humans through sensory receptions including eyes, ears, smell, taste, or contact (Parsons & Conroy, 2006). Sensory stimuli are important foundational components of gamified systems, which in most cases build primarily on images and audio (Liu, Santhanam, & Webster, 2017) and help reverberate the user's changes (Rapp, Tirassa, & Tirabeni, 2019). Therefore, in this study, we focus on the sensory receptions of sight and sound.

Regarding the evolution of gamification research, Nacke and Deterding (2017) indicated that gamification research initially asked the blanket question "does gamification work?", which is currently in a maturing stage (pp. 450–451):

If the first wave of gamification research was held together by fundamental questions of "what?" and "why?", the current wave is asking differentiated questions around "how?", "when?", and "how and when not?".

In our first field experiment on gamification for motivating eco-driving (Degirmenci, Katolla, & Breitner, 2015), we explored the impact of a gamified mobile application on energy consumption. We used energy consumption as the dependent variable of our study, which indicated how eco-efficient the participants drove. We found that gamification works for eco-driving: our experimental group who used the gamified application during test drives with a battery electric car consumed significantly less energy compared to the control group who drove without the application. In the present paper, we report on our second field experiment on gamified eco-driving, where we go one step further and examine *how* and *when* sensory stimuli in gamified systems influence users' driving behaviors. We focus on *how* design choices of visual and auditory stimuli in gamified systems inform the extent to which drivers engage in driving behavior that minimizes energy consumption by avoiding energy-intensive driving choices such as excessive acceleration and hard braking (De Vlieger, De Keukeleere, & Kretzschmar, 2000; Fonseca, Casanova, & Espinosa, 2010; Helmbrecht, Monreal, & Bengler, 2014). A combination of visual and auditory stimuli is particularly effective for real-time gamification, such as in our driving behavior context. Different transport fields like public transport might need other forms of affordances than sensory stimuli to improve energy efficiency. In our context, the driving style plays an important role in improving the energy efficiency in battery electric vehicles (Knowles, Scott, & Baglee, 2012). Prior test drives from other studies show that aggressive driving has a significant influence on energy consumption in electric vehicles, reducing up to 35 % energy through changing driving styles (Al-Wreikat, Serrano, & Sodré, 2021; Donkers, Yang, & Viktorović, 2020). While recharging effects occur through regenerative braking which provides the ability to recover the electric vehicle's kinetic energy during deceleration and convert it into electricity in order to recharge the battery (Lv, Zhang, Li, & Yuan, 2015; Qiu & Wang, 2016), the energy recovery from regenerative braking does not guarantee less energy consumption because deceleration requires acceleration to adapt to the traffic flow (Hu, Wu, & Schwanen, 2017). We have two main reasons for choosing this setting: First, about one quarter of worldwide carbon emissions is produced in the transport sector (International Energy Agency, 2018), which makes transportation a relevant field of research for environmental sustainability (Degirmenci & Breitner, 2017). Second, electric vehicles are in and by themselves a purportedly environmentally friendly choice of transportation; they are constructed more eco-effective than combustion vehicles – but they are also only eco-efficient if they are used appropriately, that is, if they are operated in a way that conservation, i.e., reduction of energy consumption, and restoration, i.e., recharging, effects occur. These two effects are primarily a question of operation, i.e., the choices an operator makes: in order to reduce energy consumption, excessive acceleration and hard braking must be avoided, if possible; similarly, for recharging, the regenerative braking system of electric vehicles, which recovers the vehicle's kinetic energy during deceleration, must be operated such that minimal heat, as in a conventional braking system, is produced.

Our study contributes to the gamified driving literature in two ways: First, we link gamification design decisions (visual and auditory stimuli) to two types of outcomes – instrumental and experiential, situated in a societally relevant application domain, eco-driving, which is a relevant domain in the field of sustainable transportation (Henfridsson & Lind, 2014), and where gamification is considered to be an important part of a gamified solution space (Günther, Kacperski, & Krems, 2020; Nousias et al., 2019). Second, our study provides important insights into the relationship between outcomes and adoption of real-time gamification in safety critical situations. Our findings suggest a trade-off between outcomes of gamified system use, which are realized through the reinforcement of desired behaviors, and the adoption of gamified systems depending on levels of enjoyment while using, and intention to use the system. We link this trade-off to the choices through which sensory stimuli are designed into a system, which implicates that the design of gamified systems requires a careful balance of visual and auditory stimuli to increase both outcomes and adoption, not just either or. Third, we focus on gamification used in mobile applications to derive implications for the widespread use of smartphones. Therefore, we investigate visual and auditory stimuli, and exclude haptic feedback. Nevertheless, we acknowledge that prior eco-driving research has addressed haptic feedback, e.g., through vibrotactile pedals (Birrell, Young, & Weldon, 2013) or virtual reality environments (Pietra et al., 2021).

First, we introduce gamification and sensory stimuli, and explain the role of driver assistance in eco-driving. Then, we develop our hypotheses, for which we draw on the concept of meaningful engagement through gamification (Liu et al., 2017). Next, we describe how we conduct our field experiment. After presenting our results and evaluating our hypotheses, we discuss our findings and their implications, and give recommendations. Finally, we address limitations and conclusions of our study and provide an outlook for further research.

2. Theoretical and practical background

2.1. Gamification and sensory stimuli in gamified systems

Presently, much attention is geared towards the use of gaming elements as a particularly promising way to enhance user engagement (Baptista & Oliveira, 2019; Behl & Dutta, 2020; Groening & Binnewies, 2019; Koivisto & Hamari, 2019; Moro, Ramos, Esmerado, & Jalali, 2019). While rewards are used in gamified systems to motivate positive behaviors, punishments have the purpose to discourage negative ones (Diefenbach & Müssig, 2019). Both rewards and punishments are typical gamification elements and have been proven to be effective to engage users in desirable behaviors (Fang et al., 2019; Gamma, Mai, Cometta, & Loock, 2021). Considering classic game elements, rewards are often used to praise the player through an explicit statement or a special sound effect; they come in the form of points or power-ups (such as becoming tall in *Super Mario Bros.* or speeding up in *Sonic the Hedgehog*), or just simply by completing a level (Schell, 2008). Punishments do the opposite: they shame the player through explicit messages (e.g., “Missed” or “Defeated!”), or with discouraging animations, sound effects, and music. They are delivered through the loss of points or fail points, terminated play (most commonly: game over), setback (when, after dying, a game returns the player to the start of a level or to the last checkpoint), or resource depletion (running out of money, goods, or ammunition), which allows the player a chance to risk consequences and makes success more valuable (Schell, 2008).

Gamification design elements in the form of points, badges and leaderboards, often referred to as PBL, have been in the focus of numerous studies (see, e.g., Ambrey & Yen, 2018; Aparicio, Oliveira, Bacao, & Painho, 2019; Dissanayake, Mehta, Palvia, Taras, & Amoako-Gyampah, 2019; Hamari, 2017; Höllig, Tumasjan, & Welpe, 2020; Landers, Bauer, & Callan, 2017; Lieberoth, Jensen, & Bredahl, 2018; Morschheuser, Hamari, & Maedche, 2019). However, none of these studies investigated the role of sensory stimuli in gamification, which is surprising given that most games are essentially narratives composed of sight and sound (Nacke, Grimshaw, & Lindley, 2010; Nandhakumar, Panourgias, & Scarbrough, 2013; Seidel et al., 2018). This lack of knowledge on fundamental gamification design building blocks has been noted by others as well: it is “not just a matter of adding PBL (points, badges, and leaderboards) to any digital task but to carefully design gamified systems that will foster desired behaviors” (Liu et al., 2017, p. 1012).

While most gamification research has a focus on visual signals of gamification, there is less literature that examines auditory elements, such as the following paper, which has analyzed differences in narrative game elements in the form of text, audio, still pictures, and video: Landers, Auer, and Abraham (2020) used a situational judgment test for assessment gamification to examine users’ conscientiousness and cognitive ability in assessment situations. While most gamification studies do not report on auditory elements of the gamified system in focus, some studies rarely report auditory stimuli, for example, the following paper has reported auditory stimuli on a marginal note: Santhanam, Liu, and Shen (2016) used a mini-game, “Who Wants to Be a Millionaire?” to gamify a university learning system, which contains auditory stimuli such as simulated applause and background music. In gamification research, there is a disproportional focus on PBL and other gamification design elements, while core components such as sight and sound, which are essential parts of *any* gamification element (Landers, 2019), have not yet been adequately researched. We take this step and examine how the design of sensory stimuli in gamified driving will influence the desired changes in users’ driving behaviors.

2.2. Eco-driving and driver assistance systems

Gamification is relevant in different fields such as education, health, crowdsourcing, or sustainability (Seaborn & Fels, 2015). Our focal setting is sustainability because gamification has been lauded as a potential way to help encourage sustainable behaviors (Shevchuk, Degirmenci, & Oinas-Kukkonen, 2019) and improve environmental conditions (Elliot & Webster, 2017). Given the importance of eco-driving for the sustainability of transportation through improved energy efficiency (Barla, Gilbert-Gonthier, Lopez Castro, & Miranda-Moreno, 2017; McConky, Chen, & Gavi, 2018; Sivak & Schoettle, 2012), it is notable that, in the emergence of research on green information systems (Gholami, Watson, Hasan, Molla, & Bjørn-Andersen, 2016), eco-driving has so far played an underrepresented role in information systems research (Henfridsson & Lind, 2014). In transportation research, however, there has been a sizable discussion on eco-driving in recent years, particularly on the subject of how driver assistance systems can improve eco-driving behaviors (see, e.g., Dogan, Bolderdijk, & Steg, 2014; Jamson, Brouwer, & Seewald, 2015; Stillwater & Kurani, 2013).

Driver assistance systems are information systems that provide relevant information to improve driver behavior, e.g., by means of adaptive cruise control, forward collision warning, driver drowsiness detection, traffic sign recognition, parking assistance, night vision, etc. (Akhlaq, Sheltami, Helgeson, & Shakshuki, 2012). Most prominently, such systems are used in a road safety scenario, where distraction is a serious issue and can lead to severe road crashes (Née et al., 2019). Besides inner cognitive or on-road distractions, particularly in-vehicle and mobile phone interactions increasingly become a hazard to drivers (Oviedo-Trespalacios, Haque, King, & Washington, 2016; Qin, Li, Chen, Bill, & Noyce, 2019). Given the important role of mobile phones in today’s world, stopping their use in vehicles appears to be unrealistic (Oviedo-Trespalacios, Briant, Kaye, & King, 2020). Therefore, a growing body of research analyzes how actually mobile phones can be used to reduce distractions (Diewald, Möller, Roalter, Stockinger, & Kranz, 2013; Orfila, Saint Pierre, & Messias, 2015; Xie, Chen, & Donmez, 2016), without additional distraction from the primary task of driving (Steinberger, Schroeter, Foth, & Johnson, 2017; Vaezipour, Rakotonirainy, Haworth, & Delhomme, 2017).

While road safety is a major concern, dedicated eco-driving assistance systems are emerging, which are developed specifically to assist users to drive more eco-efficiently and thereby reduce energy consumption (Fors, Kircher, & Ahlström, 2015; Tulusan, Steggers, Staake, & Fleisch, 2012). Most systems provide driver feedback visually (Sanguinetti, Queen, Yee, & Akanesuvan, 2020), through eco-appropriate symbolic expressions, for example, in a form of a set of green leaves, which grow and vanish according to the eco-driving performance (Meschtscherjakov, Wilfinger, & Scherndl, 2009); or by providing performance scores referring to eco-driving relevant factors such as acceleration, braking, and speed (Fors et al., 2015; Tulusan et al., 2012); or by showing eco-driving messages such as increased energy consumption due to excessive acceleration (Rouzikhah, King, & Rakotonirainy, 2013). Further elements include skill levels, for example, Orfila et al. (2015) motivate drivers to drive more eco-friendly by using a gamified mobile application, which rewards the driver to gain an additional level for an average eco-driving score greater than 70 % for five trips out of the last ten trips, and the driver is punished and loses one level if they get an average score lower than 40 % for eight trips out of the last ten. These examples show that visual sensory stimuli are the primary design elements employed in eco-driving assistance systems. Studies show that they can indeed improve the eco-driving performance and lead to higher energy reductions, however, the literature also shows that the same mechanisms become less clear once auditory signals such as sounds, beeps, or other signals are added to the visual stimuli (Hammerschmidt & Hermann, 2017).

We are interested in the two different roles that visual and auditory stimuli of gamified systems have on eco-driving in a real-time safety critical situation, in particular regarding the impact of a gamified mobile application on users' eco-driving behaviors using both visual and auditory stimuli. Our claim is that visual and auditory stimuli lead to a potential trade-off between outcomes, i.e., how eco-efficient a user driving behavior becomes, and adoption, i.e., whether or not the user is willing to continue using the gamified system while driving. In extending this challenge of a trade-off, we provide a nuanced view on distinctive impacts of visual and auditory stimuli on eco-driving behaviors and the adoption and outcomes of the gamified system.

3. Present research

Since the desirable outcome of the use of gamified systems for eco-driving is the reduction of energy consumption during vehicle operation, we draw on the concept of meaningful engagement through gamification (Liu et al., 2017) to develop our experimental hypotheses. We do so because we want to better understand how sensory stimuli in gamified driving not only affect the experience of system use but also its performance outcomes regarding increased energy reductions. The concept of meaningful engagement through gamification serves as an adequate theoretical baseline for this twofold focus because it differentiates between instrumental and experiential outcomes (Liu et al., 2017). Instrumental outcomes refer to salient utilitarian consequences situated within the context for which the system is developed, in our context the reduction of energy consumption during vehicle operation. Experiential outcomes refer to outcomes in the form of enjoyment, engagement, fun, cognitive effort, and other similar outcomes. Our research objective is to analyze a trade-off between instrumental and experiential outcomes of gamified applications to improve eco-driving behaviors. We address the following research questions: (1) How do sensory stimuli (visual and auditory) vary in gamified applications regarding their impact on instrumental outcomes (energy consumption) of eco-driving? (2) How are they distinctive when influencing experiential outcomes (perceived usefulness, ease of use, enjoyment, and intention to use)? We develop hypotheses first for instrumental and then experiential outcomes.

Because individuals have separate information-processing channels (eyes and ears) available while driving, but their capacity for seeing and hearing is limited (Baddeley & Hitch, 1974; Mayer, 2009), we propose that addressing both the visual and auditory sensory memory helps to overcome the limited capacity of users of gamified systems while driving a car. This is particularly true in a driving context because driving is a highly visual task (Birrell et al., 2013). Therefore, visual stimuli in gamified systems are competing stronger with the driving task than auditory stimuli. We further assume that drivers actively process the visual and auditory information transmitted by the gamified system, resulting in an improved integration with other knowledge regarding eco-driving goals and techniques, which eventually allows users to drive more eco-friendly. Therefore, we propose the following first hypothesis:

H1. We hypothesize that drivers receiving both visual and auditory stimuli through a gamified system during vehicle operation, would consume significantly less energy than those receiving no stimuli (control group) or visual stimuli only.

Besides instrumental outcomes in the form of energy reduction, the integration process of mental representations of visual and auditory stimuli also leads to experiential outcomes. Both perspectives are relevant to the use of a gamified system for eco-driving: such a system is serious, i.e., it contains elements of utilitarian nature—its fundamental purpose is to assist users to improve their eco-driving performance. However, as game elements such as taking up challenges (like growing green leaves in Meschtscherjakov et al.'s (2009) study) or collecting points (such as providing eco-performance scores in Fors et al.'s (2015) or Tulusan et al.'s (2012) study) are increasingly added to eco-driving assistance systems, there is also a notable fun aspect in the process of using such systems, in turn highlighting a hedonic appeal of the system. To understand which of the serious and fun aspects feature more strongly in the experience of users and the formation of their intention to use such a system, we draw on works that provide concepts to explain utilitarian (Davis, 1989) and hedonic (van der Heijden, 2004) technology adoption to conceptualize experiential outcomes from the use of gamified systems.

Specifically, we draw on the constructs of perceived usefulness and perceived ease of use, key determinants of intention to use utilitarian technologies (Althuizen, 2018; Davis, Bagozzi, & Warshaw, 1989), a relationship that explains why individuals accept or reject an information system. The origins of perceived usefulness and ease of use are ascribed to the workplace environment, when Davis (1989) investigated how system use enhances an individual's job performance and be free of effort. We consider perceived usefulness and ease of use in the context of eco-driving performance, more specifically, the performance of improving acceleration and braking behavior. Outside this productivity-oriented context, van der Heijden (2004) analyzed system use in a hedonic context in which systems "aim to provide self-fulfilling rather than instrumental value to the user, are strongly connected to home and leisure activities, focus on the fun aspect of using information systems, and encourage prolonged rather than productive use" (p. 695), conceptualized in the notion of perceived enjoyment, which captures "the extent to which the activity of using the computer is perceived to be enjoyable in its own right, apart from any performance consequences that may be anticipated" (Davis, Bagozzi, & Warshaw, 1992, p. 1113).

With these concepts defined, we assume that, in general, the provision of any sensory stimuli will likely be perceived as somewhat useful. This is because engaging in ecologically sustainable behavior requires relevant information about the environmental impact of personal decisions (Watson, Corbett, Boudreau, & Webster, 2012). Eco-driving assistance systems have the capability to provide such information through visual and auditory feedback to the driver (Hermsen, Frost, Renes, & Kerkhof, 2016). For example, a system equipped with a visual display showing the acceleration and braking performance enables drivers to adjust their driving behaviors, which reduces the level of energy consumption and thus improves on eco-driving (De Vlieger et al., 2000; Fonseca et al., 2010). Thus, ex ante, visual stimuli elevate usefulness perceptions because the system can support eco-driving through the provision of accurate, meaningful, timely, and actionable information.

Due to an increasing complexity of the main task of driving, any additional interaction while driving can amplify distraction for the driver (Vaezipour et al., 2017). In a road safety scenario, distraction is the “diversion of attention away from activities critical for safe driving toward a competing activity, which may result in insufficient or no attention to activities critical for safe driving” (Regan, Hallett, & Gordon, 2011, p. 1776). Adding auditory stimuli to visual stimuli therefore diverts drivers’ attention away from the main task of driving toward the competing activity of paying attention to the gamified system, and as a consequence lead to increased distraction for the driver (Fors et al., 2015; Rouzikhah et al., 2013). One explanation for this effect is that auditory feedback is more difficult to ignore than visual feedback (Kircher, Fors, & Ahlstrom, 2014). Visual-auditory stimuli literally impede users to actively choose the moment of information gathering themselves, whereas visual-only stimuli can be considered, i.e., looked at, at the disposition of the user (Meschtscherjakov et al., 2009). We acknowledge that this provides a conflict between the driver’s attention on the road and their attention to the gamified system that is required to make the visual and auditory stimuli as effective as possible. As a result, we assume that participants experience lower intentions to use the gamified system compared to participants who are not exposed to an auditory signal because their attention is drawn away from the road toward the gamified system. We thus anticipate that users’ intentions are affected by how useful, easy to use, and enjoyable they perceive the gamified system to be. We propose the following second hypothesis:

H2. We hypothesize that drivers receiving both visual and auditory stimuli through a gamified system during vehicle operation, would experience (a) perceived usefulness, (b) perceived ease of use, (c) perceived enjoyment, and (d) intention to use significantly lower than those receiving visual stimuli only.

4. Research design and methods

4.1. Research design

We conducted a field experiment, which boasts strong ecological validity (Bordens & Abbott, 2018), and thus makes an adequate choice of our research design. As the setting for our experiment, we settled on the operation of a battery electric car with the help of a gamified mobile application. We used one between-group factor with three levels: without gamified application (control group), with gamified application visual stimuli only (visual-only group), and with gamified application adding auditory cue to visual stimuli (visual-auditory group). While adding an auditory cue to visual stimuli might appear as a small design change, the outcome is far from trivial: “games are complex, dynamic systems, in which even small design changes can have huge impacts on the experience of players” (Rapp, Hopfgartner, Hamari, Linehan, & Cena, 2019, p. 2). We employed energy in kilowatt hours (kWh) per 100 km consumed by the battery electric car as the dependent variable.

4.2. Treatment

For the treatment of the experiment in order to monitor excessive acceleration and hard braking, an application called *Smooth Driver* by Jettysoft (Apple, 2014) was chosen as the treatment. The application provided accurate, practical, and relevant usability as well as the motivation to drive more energy-efficiently by giving the task to drive without dropping a ball out of a visualized bowl, and thus providing a gamified solution to enhance eco-driving (see Apple (2014) for screenshots of the gamified application).

While there were three levels of difficulty to choose from, the application was set to normal mode. Prior to the test drives, seven rehearsal drives were performed in order to pretest the applicability of the mobile application. As part of the pretest, the beginner, normal, and master mode of the application was tested in order to find the accurate level of difficulty. The beginner mode extends the size of the bowl, whereas the master mode reduces the size making the task more difficult to perform. The choice of the mode implicates a balance between driving comfort and energy efficiency. For the experiment, based on the feedback from participants of the rehearsal drives, the normal mode was chosen in order to ensure driving comfort and also to encourage energy-efficient driving.

The gamified application provided visual and auditory sensory information and allowed us to realize visual-only and visual-auditory conditions. We established a link between the application’s objective of keeping the ball inside the bowl and a lower energy consumption because we assumed that participants would reduce excessive acceleration and hard braking to achieve the objective. Touching the screen while driving was not required to use the application, reducing the risk of distraction to a reasonable minimum. The mobile phone on which the application was displayed had a screen size of 4 in. on the diagonal and was mounted on the car’s central panel using a suction cup mount. This ensured to comply with the federal road traffic regulations, which specify that it is not allowed for drivers to hold mobile phones in their hands while driving. To that end, it is important to note that we did not only provide the opportunity for participants to drive ecologically efficient but also safely, which allowed for eco-safe driving (Vaezipour et al., 2017). To add further to the safety of the protocol, we chose *Smooth Driver* because the application has not only been designed to enhance energy efficiency but also to improve vehicle safety. The developers state that using the application helps to reduce the risk of

Table 1
Gamification design in *Smooth Driver*.

Gamified system	Gamification elements
Gamification objects	• *Grey bowl:* a grey bowl defines the area where the challenge is to keep a red ball inside the bowl *Red ball:* a red ball illustrates the intensity of the driving behavior where excessive acceleration and hard braking is likely to push the ball outside of the bowl *Fail points:* fail points are visualized through digit numbers *Sound signal:* a sound signal is produced in the form of a beep lasting 1000 ms on a frequency of 2000 Hertz
Gamification mechanics	• *Conferring fail points:* for each time the ball drops out of the bowl, the driver receives a fail point *Auditory feedback:* the sound signal informs the driver of a fail point, which provides the incentive to drive more smoothly

traffic accident, such as the risk of nose-to-tail crashes, which is a common type of accident, by monitoring acceleration and braking behavior (Apple, 2014). Nevertheless, for safety reasons, we stress that real-time gamified applications in safety critical situations should only be started before starting to drive and that the driver should always keep the eyes on the road while driving. In case of a near-crash situation, research suggests that a distinction is required between emergency braking as a result of inadequate anticipation of road or traffic situations, and emergency braking due to circumstances that are out of the driver's control such as traffic accidents caused by other drivers (Zavalko, 2018). Since eco-driving trains skills through anticipated driving including smooth acceleration and braking, the former is considered to involve low levels of eco-driving skills, while the latter occurs seldom.

The application includes two gamification elements: (1) a challenge is offered through a grey bowl with a red ball inside, which rests in the middle of the bowl in its idle position. An abrupt change in velocity or direction moves the ball out of the bowl, while the magnitude of velocity change is critical for energy-efficient driving. The goal of the user is to drive without dropping the ball out of the bowl, which engages the user to drive in a way that avoids excessive acceleration and hard braking in order to keep the ball inside of the bowl; and (2) each drop of the ball outside the bowl results in a fail point as a form of punishment, which increases the challenge of play (Schell, 2008). Collecting as few fail points as possible discourages the driver from excessive acceleration and hard braking, and motivates them to drive more eco-friendly. Both gaming elements are visual in nature, however, importantly for our purposes, the application allows the optional provision of an auditory signal produced for each fail point, in the form of an auditory stimulus, a beep, lasting 1000 ms on a frequency of 2000 Hertz.

Table 1 shows the gamification elements of *Smooth Driver*, where two main categories are used to classify the design of the gamified system, i.e., gamification objects and mechanics (Liu et al., 2017). Gamification objects are "the basic 'building blocks' of a gamified system, which typically include items, characters, scripts, visual assets, and so on" (Liu et al., 2017, p. 5). They are classified into two types of experiences: sensory experiences such as images, audios, videos, animations, and multimedia (called aesthetics in other gamification taxonomies); and cognitive experiences such as stories, puzzles, and plots (called narratives in some taxonomies). Gamification mechanics refer to "the rules that govern the interaction between users and game objects" (Liu et al., 2017, p. 6). For example, a gamified system could contain points as an object, and the mechanic could be the rules for awarding the points to the user. Other mechanics may provide rules for chance elements, user choices, levels, leaderboards, badges, guilds, trading, and social interactions. The combination of gamification mechanics with actions taken by users, results in user-system interactions (called dynamics in some taxonomies).

This allowed us to create a visual-only group, where participants were only exposed to the visual elements of the gamified application; and a visual-auditory group, where the auditory signal was provided in addition to the visual elements. We did not focus on how the drivers performed in the game because the gameful experience was in the focus of the user–system interaction (Liu et al., 2017), and win-lose situations have been shown to have no effect on enhancing instrumental task outcomes (Hammedi, Leclercq, Poncin, & Alkire, 2021).

4.3. Measurements

For our independent variable, we manipulated (1) the presence and absence of the gamified application, and (2) the inclusion/exclusion of the sound signal of the application to realize our experimental groups. We measured our dependent variable for instrumental outcomes, energy consumption, by tracking energy in kWh/100 km consumed by the battery electric car with the vehicle's built-in telematics system. This allowed to compare the driving performance between the control group, visual-only group, and visual-auditory group. The accuracy of the vehicle's built-in telematics was confirmed by verifying the energy in kWh/100 km through the electric car's online platform service, which provides connectivity and diagnostic features as well as a battery management system.

In addition to measuring the dependent variable for instrumental outcomes, we also measured latent variables for experiential outcomes. We measured them with reflective multiple-item survey scales, drawn from pre-validated measures. Perceived usefulness was measured with item scales from van der Heijden (2004) who originally used the scale in a movie community platform context. We adapted the scale to fit to eco-driving behavior, particularly acceleration and braking behavior, to correspond to the gamified application in use. Perceived ease of use was measured with item scales from Venkatesh and Davis (2000), and perceived enjoyment was adapted from Cheung, Chang, and Lai (2000). Intention to use was measured using the three-item scale from Pavlou (2003), who originally used the scale to measure transaction intentions in an e-commerce context. Here, too, we brought the scale to our gamified application context to ask whether the user intended to use the application in the future. Items were measured using seven-point Likert

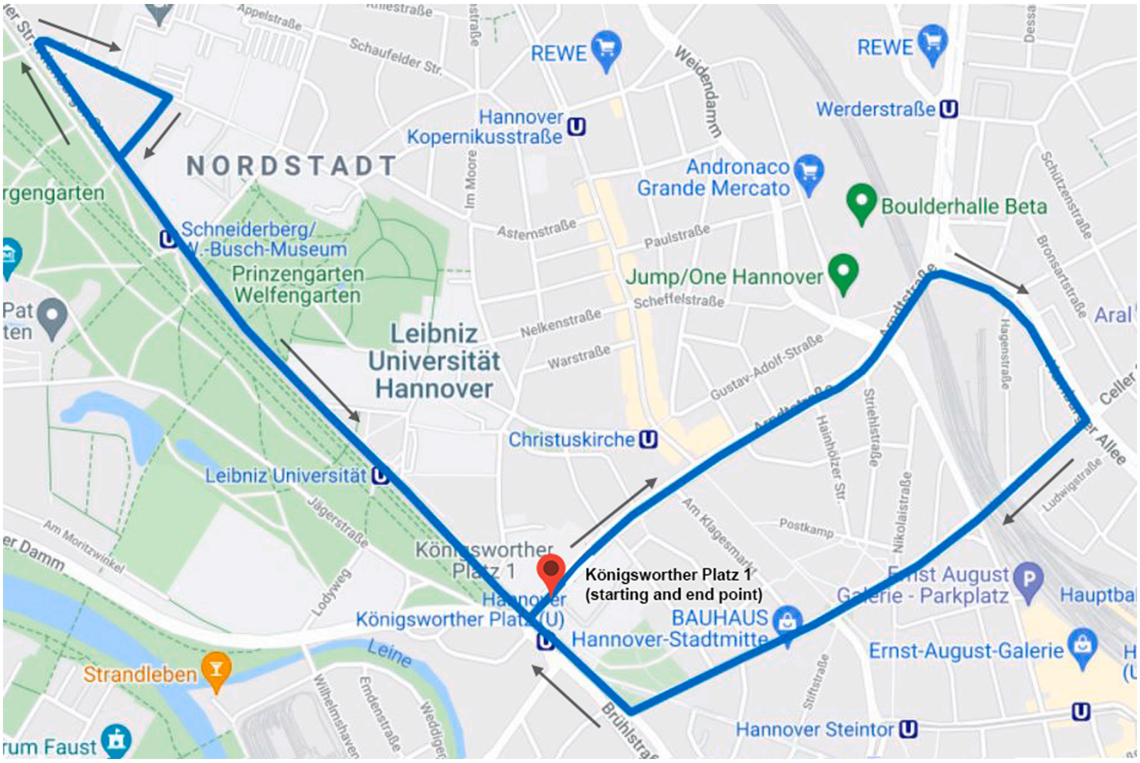

Fig. 1. Predetermined route for the test drives with a battery electric car. Map data ©2021 GeoBasis-DE/BKG (©2009).

scales ranging from highly disagree to highly agree, and with seven-point semantic differential scales. The full instrument is provided in Table A1 (see Appendix).

4.4. Participants

We recruited 63 participants via social networking sites, email, and personal recruitment through professional and university campus networking, who were selected by offering the opportunity to take a test drive with a battery electric car. In our between-group experiment, one participant only did one test drive, resulting in 63 test drives with 63 different participants. We engaged a student assistant who conducted the test drives and survey procedure with participants. Student participants were students from a large university of the city of choice, and all other participants were from the region of the city. The demographics of the participants are provided in Table A2 (see Appendix). Participants drove a total of about 378 km, which took more than 15 h overall. An *a priori* power analysis using G*Power (Faul, Erdfelder, Buchner, & Lang, 2009) recommended that a sample size of 42 participants was required for three groups to detect effect size f of 0.50 (equivalent to partial eta-squared (η^2) of 0.20), with statistical power of 0.80 at alpha level of 0.05.

4.5. Procedures

We carried out the field experiment in four phases: assignment, introduction, driving, and post-test. We randomly assigned participants to either the control group, visual-only group, or the visual-auditory group. For reasons of regional proximity, the test drives were performed in the city of Hanover, Lower Saxony, Germany. The test route was determined as follows: the starting point was the campus of the School of Economics and Management of the University of Hanover, Königsworther Platz 1, continuing to Hamburger Allee, turning right to Celler Straβe until Brühlstraβe, then Nienburger Straβe and over Callinstraβe and Kniggestraβe finally back to Königsworther Platz 1 (see Fig. 1).

The route for the test drives was a mix of 50 km/h and 30 km/h tempo limit city traffic and had a length of approximately 6 km with an average duration of around 15 min per test drive. Average speed was 22.8 km/h for the control group, 21.1 km/h for the visual-only group, and 20.9 km/h for the visual-auditory group. These values are within expected ranges because they fall within average city speed and we expect that drivers who are not under the influence of the *Smooth Driver* application will tend to drive more aggressively, which typically influences drivers to drive at higher speeds resulting in higher energy consumption (De Vlieger et al., 2000). Average outside temperature was 11.3 °C and average time of day was 12:30 pm. Before each test drive, the participants were briefly introduced to the test vehicle and were instructed to drive normally. They did not know that the energy consumption of the test drives was in focus

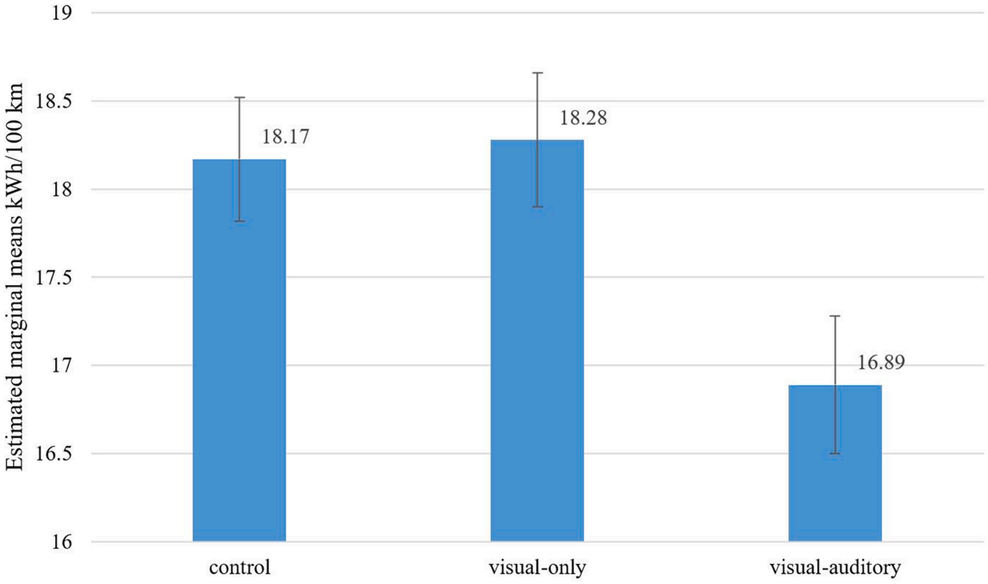

Fig. 2. ANCOVA estimated marginal means including standard error bars (covariate: auxiliary equipment).

Table 2
ANCOVA contrast results.

Dependent variable	Group contrast	Mean difference	Std. error	Sig.	95 % confidence interval for difference	
					Lower bound	Upper bound
Energy consumption	control vs visual-only	–0.10	0.51	0.84	–1.11	0.91
	control vs visual-auditory	1.29	0.54	0.02	0.20	2.38
	visual-only vs visual-auditory	1.39	0.58	0.02	0.23	2.55

Covariate: auxiliary equipment.

of the study and they were not informed which group they were assigned to. We started with the *control* group (no stimuli), which was largely completed between 12 August to 19 August 2015 and some further test drives between September and December 2015 with this group (with an average outdoor temperature of 19.8 °C in August 2015, average energy consumption of auxiliary equipment of 2.27 kWh/100 km, and an average time of 14m22s); the *visual-only* group was completed from 20 November to 2 December 2015 (with an average outdoor temperature of 8.9 °C in November 2015, average energy consumption of auxiliary equipment of 1.73 kWh/100 km, and an average time of 16m45s); and the visual-auditory group from 9 December to 19 December 2015 (with an average outdoor temperature of 8.9 °C in December 2015, average energy consumption of auxiliary equipment of 4.58 kWh/100 km, and an average time of 16m48s).[1] The procedures for controlling the covariate of auxiliary equipment was thus necessary to eliminate systematic weather bias that might have otherwise biased the results. After completion of each test drive, participants were asked to complete a paper survey that measured our four key latent constructs: perceived usefulness, ease of use, enjoyment, and intention to use.

5. Results and findings

5.1. Evaluation of instrumental outcomes

To evaluate instrumental outcomes, we conducted an analysis of covariance (ANCOVA) using SPSS, with energy consumption as the dependent variable, the treatment across the three groups as the independent variable, i.e., the control group, visual-only group, and visual-auditory group, as well as auxiliary equipment as the covariate. The assumptions of ANCOVA to ensure statistical robustness according to Hair, Black, Babin, and Anderson (2019) were met.

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[1] We used historical data for the weather in Hanover, Germany from the German Meteorological Office (Deutscher Wetterdienst): https://www.dwd.de/DE/leistungen/klimadatendeutschland/klimadatendeutschland.html.

Table 3
Principal component analysis.

Construct	Item	Component				Cronbach's alpha	Average variance extracted (AVE)
		1	2	3	4		
Perceived usefulness	PU1	**0.71**	0.12	0.17	0.47	0.92	0.66
	PU2	**0.87**	0.18	0.04	0.29		
	PU3	**0.87**	0.14	0.14	0.25		
	PU4	**0.78**	0.22	0.35	0.18		
	PU5	**0.83**	0.16	0.27	0.16		
Perceived ease of use	PEOU1	0.42	**0.62**	0.23	–0.13	0.83	0.64
	PEOU2	0.19	**0.84**	0.15	–0.10		
	PEOU3	0.11	**0.86**	0.23	0.12		
	PEOU4	0.08	**0.85**	0.10	0.16		
Perceived enjoyment	PE1	0.12	0.21	**0.88**	0.21	0.89	0.59
	PE2	0.30	0.20	**0.70**	0.45		
	PE3	0.15	0.21	**0.84**	0.25		
	PE4	0.46	0.25	**0.64**	0.14		
Intention to use	INT1	0.33	–0.01	0.37	**0.82**	0.95	0.71
	INT2	0.33	0.08	0.39	**0.82**		
	INT3	0.24	–0.01	0.14	**0.89**		
Rotation sums of squared loadings	Total	4.16	2.89	3.06	2.94		
	% of variance	25.98	18.06	19.11	18.37		
	Cumulative %	25.98	44.04	63.15	81.52		

Table 4
Correlation matrix.

	PU	PEOU	PE	INT	KWH	SEX	AGE	PRO
PU	**0.81**							
PEOU	0.42	**0.80**						
PE	0.58	0.48	**0.77**					
INT	0.61	0.18	0.63	**0.84**				
KWH	0.03	–0.05	–0.12	–0.08	**1.00**			
SEX	0.08	0.07	–0.10	–0.28	0.15	**1.00**		
AGE	–0.02	–0.21	–0.02	–0.04	–0.12	–0.07	**1.00**	
PRO	–0.18	–0.06	–0.15	–0.16	–0.10	0.16	–0.42	**1.00**

Notes: PU = perceived usefulness, PEOU = perceived ease of use, PE = perceived enjoyment, INT = intention to use, KWH = kilowatt hours, SEX = gender, AGE = age, PRO = profession; value on the diagonal is the square root of average variance extracted (AVE).

Table 5
Means and standard deviations of survey results.

Dependent variable	Group	Mean	Std. deviation	N
Perceived usefulness	Visual-only	3.70	1.31	20
	Visual-auditory	3.04	1.17	21
Perceived ease of use	Visual-only	4.25	1.45	20
	Visual-auditory	4.11	0.91	21
Perceived enjoyment	Visual-only	4.48	1.15	20
	Visual-auditory	3.38	1.30	21
Intention to use	Visual-only	3.79	1.22	20
	Visual-auditory	2.51	1.38	21

Fig. 2 shows means and standard errors between the groups for the dependent variable. Estimated marginal means are lower for the visual-auditory group compared to both the control group and the visual-only group, indicating that less energy has been consumed for the visual-auditory group. Contrast results in Table 2 further show significant variances between the visual-auditory and control group as well as the visual-auditory and visual-only group, which is in line with hypothesis 1, but no significant variances between the visual-only group and the control group.

5.2. *Evaluation of experiential outcomes*

To evaluate differences in experiential outcomes, we first conducted a factor analysis as a dimensional reduction method using the

Table 6
MANOVA results for survey constructs.

Dependent variable	Sum of squares	df	F	Sig.
Perceived usefulness	2.70	1	2.76	0.11
Perceived ease of use	0.10	1	0.09	0.77
Perceived enjoyment	6.91	1	7.94	0.01
Intention to use	7.42	1	8.92	0.01

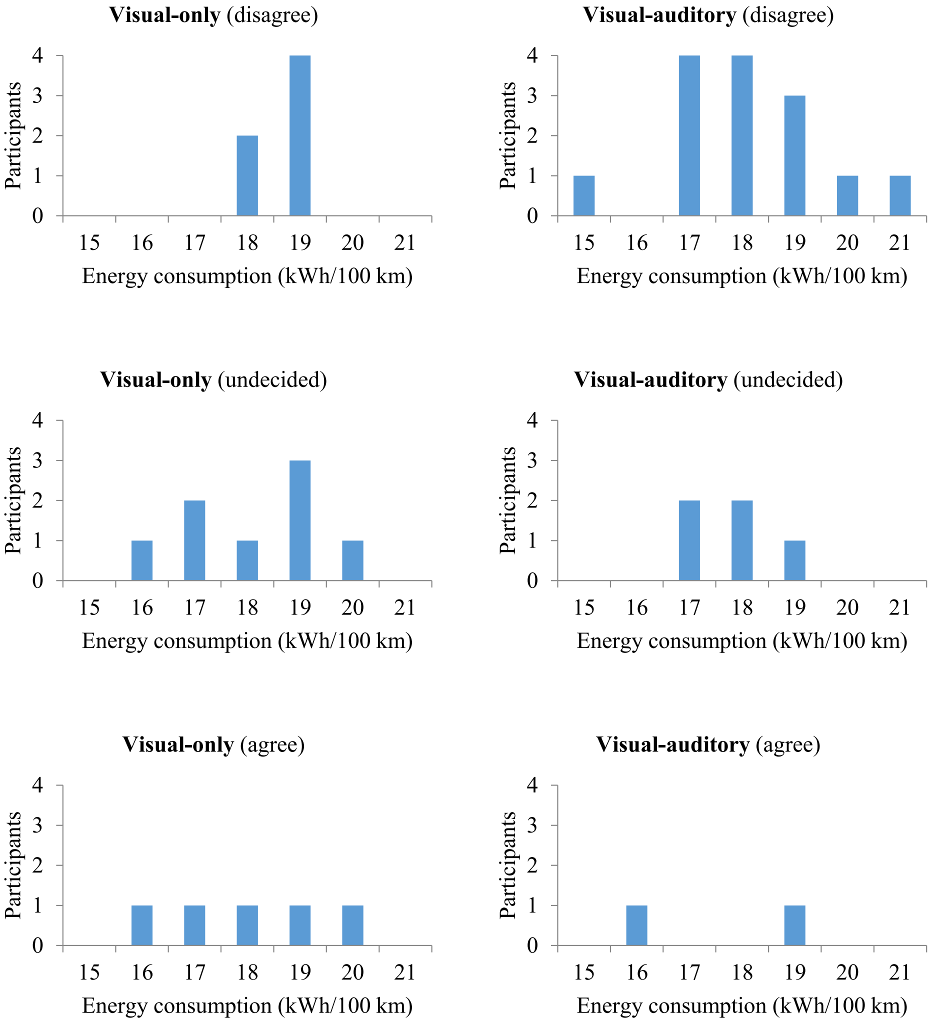

Fig. 3. Split histogram.

principal component analysis with varimax rotation as the extraction method. Results of the factor analysis showed that the measurement items loaded between 0.62 and 0.89 on their respective constructs, thus exceeding the recommended value of at least 0.50 and demonstrating adequate indicator reliability and convergent validity (Hair et al., 2019). The internal consistency of the scales through Cronbach's alpha ranged from 0.83 to 0.95, which were exceeding the recommended value for construct reliability of at least 0.70, thus meeting criteria for internal consistency (Hair et al., 2019). Average variance extracted (AVE) ranged from 0.59 to 0.71, exceeding the recommended lower limit of 0.50 and thus indicating convergent validity (Fornell & Larcker, 1981). All items loaded more highly on their constructs than any other constructs, and in all cases the items loaded above 0.62 and the differences were greater than 0.18. Table 3 shows all loadings and cross loadings of the principal component analysis, as well as Cronbach's alpha and AVE values. The square root of the AVE for each construct was larger than the correlation of the construct with any other constructs in the model, which demonstrated discriminant validity (Fornell & Larcker, 1981) (see Table 4).

To examine the between-group differences in construct means between the experimental groups who used the gamified mobile application during test drives (visual-only and visual-auditory group), we ran a multivariate analysis of variance (MANOVA). Table 5 shows means and standard deviations for both groups, indicating that perceived usefulness, ease of use, enjoyment, and intention to use were rated higher by the visual-only group. The results from the MANOVA analysis summarized in Table 6 show that two of the four construct mean differences were statistically significant at $p < 0.01$.

We present two main findings regarding experiential outcomes:

1. For the visual-only group, perceived usefulness and ease of use were evaluated higher than for the visual-auditory group, but these differences were not statistically significant at a p-value of 0.11 for perceived usefulness, and a p-value of 0.77 for perceived ease of use. Thus, hypotheses 2a and 2b were not supported by our results.
2. We found statistically significant differences between the visual-only and visual-auditory group at a p-value of 0.01 for both perceived enjoyment and intention to use. Both constructs were evaluated significantly higher by the visual-only group compared to the visual-auditory group. Our results are in line with hypotheses 2c and 2d.

Overall, the results show that there are no significant differences of perceived usefulness between the visual-only group (mean = 3.70) and the visual-auditory group (mean = 3.04), as well as of perceived ease of use between the visual-only group (mean = 4.25) and the visual-auditory group (mean = 4.11). However, there are significant differences of perceived enjoyment between the visual-only group (mean = 4.48) and the visual-auditory group (mean = 3.38), as well as of intention to use the gamified application between the visual-only group (mean = 3.79) and the visual-auditory group (mean = 2.51). This suggests that adding auditory cues to visual stimuli partly influenced the experiential outcomes in our experiment, where it had no significant effect on perceived usefulness and ease of use; however, participants' perceived enjoyment and intention to use significantly decreased when adding auditory cues.

To visualize the relationship between participants' intention to use the gamified application and energy consumption, we created a split histogram of the dependent variable energy consumption for the visual-only and visual-auditory group, showing differences of the intention to use the gamified application (see Fig. 3). We have focused on the relationship between participants' intention to use and the actual behavior (energy consumption), because intention to use is considered to be a central predictor of actual behavior (Ajzen, 1985; Ajzen & Fishbein, 1980). To calculate the level of agreement, "agree" categories were combined to calculate the frequency of agreement, and "disagree" categories were combined to calculate the frequency of disagreement. The frequency of the mid-point was used to report "undecided". The split histogram confirms our main insight that participants from the visual-only group expose higher intentions to use the gamified application; however, they consume more energy the more they agree to use the application, compared to participants from the visual-auditory group.

6. Discussion, implications, and recommendations

We carried out a field experiment to get insights about both instrumental and experiential outcomes on eco-friendly driving from using a gamified mobile application providing two different levels of sensory stimuli. Our data analysis of the instrumental outcomes showed that using this application leads to a significant reduction of energy consumption. Our results and findings suggest that real-time gamification in safety critical situations can improve eco-driving behaviors, i.e., reduce energy consumption significantly. However, comparing the instrumental to the experiential outcomes, we notice a new by-product to this effect: participants from the visual-auditory group perceived the application to be less enjoyable and in turn reported lower intentions to use the application compared to participants from the visual-only group. Together, our results and findings indicate that gamified driving can improve user behavior such that less energy is consumed if they are designed such that the experience of using the gamified application is enjoyable and thus drivers are willing to use the application – if the sensory stimuli are over-engineered, so to speak, then outcomes can be improved but adoption is likely hampered. Prior studies acknowledge that providing sensory stimuli to the driver effectively to change their driving behavior without provoking cognitive overload is not a simple task (Pietra et al., 2021).

Our findings contribute to several ongoing discussions about gamified driving. First, to the ongoing discussion in the gamified driving literature regarding a trade-off between outcomes and adoption, we provide deeper insights into the relationships between visual and auditory stimuli on the one hand, and the adoption of gamified systems in a real-time safety critical situation on the other. Our results show that the gamified application offers a more enjoyable user experience for the visual-only group who tend to accept the application more, however, the visual-auditory group consumes less energy although users' perceived enjoyment of using the application is significantly lower. These findings lead to a stance that creates the challenge to develop applications in gamified driving that appeal to a visual display enhancing instrumental outcomes, but also which does not neglect to consider whether to include auditory stimuli that users perceive enjoyable and thus are more likely to use the gamified application. This suggests that relevant design concepts for real-time gamification are required, which give directions to design gamified systems more efficiently to enhance both outcomes and adoption of gamified eco-driving.

Second, to the literature on sensory stimuli, we show that visual and auditory stimuli relate differently to instrumental and experiential outcomes. While visual-only stimuli increase the adoption of the gamified application, combined visual-auditory stimuli lead to higher energy reductions. This insight gives new directions for research on sensory stimuli that adding auditory to visual stimuli can help increase engagement to drive more eco-friendly. However, a misbalance between outcome and adoption can lead to a decline in interest and intended use of the system. We suggest further research to analyze the trade-off between outcomes and adoption of systems using both visual and auditory stimuli.

Our findings provide implications for research in gamified driving regarding two aspects: gamification design and sensory stimuli. The implications regarding gamification design come from the way we operationalized the system in our study. We focused on a challenge (keeping a red ball inside of a grey bowl) and fail points (which were dispensed for each drop of the ball). Naturally, there are many different and other ways through which a system might be gamified (see, e.g., Blohm & Leimeister, 2013; Bui, Veit, & Webster, 2015; Kankanhalli, Taher, Cavusoglu, & Kim, 2012; Zichermann & Cunningham, 2011). A logical extension of our work is thus to analyze further design elements beyond our real-time safety critical context such as leaderboards and badges, competition and social comparison, as well as storytelling and discovery, just to name a few. For example, leaderboards and badges, which involve competition and social comparison, could enhance not only motivation but also instrumental outcomes at the same time, because these elements could improve users' driving behavior without overly distracting from traffic. A result of this might provide an argument that real-time feedback is inferior to ex-post reporting (e.g., at the end of a day or a route). Other ways to continue along the ideas of our framework relate to including cognitive experience elements such as storytelling and discovery in addition to sensory experience elements that we focused on. For example, building an environmental related story around the task and allowing users to discover the environmental impact of their future behaviors might provide ex-ante effects (e.g., before driving a route).

To the aspect of sensory stimuli, broadly, our results and findings support the contention that gamified systems can assist at least one of the environmental challenges (energy consumption). Yet, the key insight is that they do so in a more nuanced way: the presence of the auditory signal decreases the intention to use the system, thereby adversely affecting the potential broader environmental gain. Together, our results and findings inform a trade-off between outcomes and adoption of real-time gamified driving to support environmental sustainability: the level of outcomes and adoption vary based on the extent to which sensory stimuli are designed into a system, and a careful balance must be struck to increase both impact (instrumental outcomes) and significance (in terms of widespread diffusion). Therefore, we suggest that sensory stimuli should be chosen such to maximize both adoption and outcomes. This is particularly challenging in scenarios where the sensory stimuli are highly competing with the main task, where the desirable behavior change is motivated by the gamified system. In the context of this study, the main task is driving, which is highly visual. For technology use, this implies that the impact of various sensory stimuli on experiential and instrumental outcomes need to be taken into consideration in technology use studies. Researchers can use our research design to investigate how diverse sensory stimuli lead to varying results and findings. In simple terms, in order to advance the understanding of sensory stimuli in gamified driving, we need to explore which combination of the stimuli works best in which user, task, and technology context. In an eco-driving context, a further exploration of the design of sensory stimuli in gamified systems will need to be addressed in order to impel the role that gamification can play in reducing energy consumption. The differences and similarities of the investigated scenario (eco-driving) to other relevant fields where gamification is applied should be considered. While driving is a highly visual task, for example, in a teaching and learning scenario, a lecture is a highly auditory task where the educator verbally presents the lecture content to the students. Here, the auditory stimuli in gamified systems would compete with the main task of listening to the lecturer. Another example is a gamified fitness environment, where the user might be too busy to look at the mobile phone but could use a smartwatch for visual gamified feedback, for example, while running. In contrast to driving, auditory stimuli might not be too distracting in gamified fitness unless severe consequences are possible, such as in high-risk sports like climbing or parkour, where fatal accidents can occur due to distraction and inattention similar to driving. In general, gamification design elements need to fit with the target system including the user, task, and technology to create behavioral changes and produce desired user–system interactions (Liu et al., 2017).

There are several advantages and disadvantages of our experimental design. Advantages include (1) the inclusion of a control group as the baseline, which allows to compare the baseline with the visual-only and visual-auditory conditions; and (2) our choice of a battery electric car, which offers the advantage of providing a precise measurement of energy consumption through built-in telematics and a battery management system. In terms of disadvantages, we acknowledge (1) the limited experience of our participants driving a battery electric car, which presented a new situation for them but at the same time motivated them to participate, and (2) the limited generalizability of our results beyond the driving context because driving is a highly visual task, which, in turn, increases the relevance of implications for gamified eco-driving.

7. Limitations

First, in order to shift between our experimental groups, we used a specific type of auditory stimulus, namely that of a monotonous sound signal produced by the gamified application. We cannot rule out that other types of sound signals lead to different results and findings. Since our interest was to discourage drivers from excessive acceleration and hard braking, we chose to use an existing gamified application including the gamification element of punishment in the form of visual fail points and a discouraging sound signal to increase the challenge of avoiding to lose the ball from the bowl. To the contrary, using sounds for rewards instead of punishments could lead to different results regarding the experimental outcome. However, this would require to change the challenge. Instead of punishing the driver for each lost ball, the driver could be motivated by keeping the ball inside the bowl for each ten seconds to collect points accompanied by rewarding sound effects. Further research could conduct experiments including different conditions where two types of sounds are compared (punishment vs reward), the inclusion of an eye-tracker, or the application of a second, different scenario with another primary task.

Second, our field experiment was conducted in a large state capital city in Europe. Measures in other cities and cultures may lead to different results. This can be due to several reasons, including different traffic and routes, as well as different values and beliefs due to cultural differences, but also due to diverse effects through sensory stimuli.

Third, in terms of generalizability, our results are bounded to the demographic characteristics of our sample. Most of the participants were male students and under 30 years old, hence, care must be taken when choosing an approach to generalize the findings beyond this population.

Fourth, considering the precision of sample estimates, which is mainly affected by the sample size (Baroudi & Orlikowski, 1989), we draw attention to our relatively small sample size ($n = 63$). This sample size was sufficient to run the tests described. However, it is clearly not large enough to examine small effects. Still, in terms of the balance between statistical power and the investigator's resources (Cohen, 1992), test drives under controlled conditions require a high amount of effort and time. Our participants drove a total of approximately 378 km in more than 15 h overall. Regarding the supervision of the test drives and survey administration, this resulted in a high amount of effort and time required to conduct the test drives and survey administration.

Fifth, we focus on short-term effects, however, fatigue effects provide further prospects for future research. Gamified systems might be used to a certain degree of usage frequency until fatigue occurs because a consolidation of desired behaviors might eventuate. Conducting a longitudinal experiment to analyze long-term effects could provide new useful insights.

Sixth, we analyze the effect of sensory stimuli in a gamified eco-driving context. An experiment outside the challenging driving scenario has the potential to provide insights with less potential confounds and limitations (e.g., traffic and weather conditions). While our field experiment in contrast to simulator studies provides higher external validity because the extent of generalizability to real-life situations is higher, internal validity can be improved by replicating our study in a simulator environment and by conducting a field experiment in other non-driving contexts. However, in contrast to a safe simulation, the real-world evaluation of gamifying an activity where the risk profile is real allows to conduct real-time gamification in safety critical situations, as performed in our study.

8. Conclusions and outlook for further research

We examined how two types of sensory stimuli, visual and auditory, in gamified systems assist drivers to reduce their energy consumption during vehicle operation. We uncovered a trade-off between the instrumental and experiential outcomes of gamified driving for environmental sustainability. The results and findings of our experiment showed that real-time gamification in safety critical situations can engage users in environmental driving to reduce energy consumption, however, an inaccurate balance between visual and auditory stimuli can lead to a decrease of user adoption. Together, our findings show that while gamified systems enable users to improve their eco-driving behavior, sensory stimuli help to enhance or lead to diminish the experience of vehicle operation depending on the types and combinations of stimuli designed into a system. Our results and findings serve as a basis for future strategies for the design of successful applications in gamified driving, which ideally increase user engagement and create desired behaviors.

Given the underrepresented role of sensory stimuli in current gamified driving research, we propose that more attention should be given to core components including sight and sound, which are essential parts of *any* gamification design element (Landers, 2019). Most studies focus on visual stimuli only, which are legitimate in their own rights. Our study shows that besides sight, the sound of gamified systems can substantially influence the way sensory stimuli are perceived by users of gamified systems, which, eventually, can have a substantial impact on the desired behavior. Thus, we concur with Rapp et al.'s (2019) view that even small design changes in gamified systems can have huge impacts on the user experience. Our study further shows that it is not only one or the other sensory stimuli, but the combination that provides implications for design choices of gamified systems. We recommend that further research considers visual and auditory stimuli for diverse gamification design elements, such as in our research regarding visualized fail points accompanied by an auditory beep signal, or with regard to other studies, e.g., Landers et al.'s (2020) study, where an auditory narrative game element helps test-takers in assessment situations; or Santhanam, et al.'s (2016) study, where an auditory simulated applause emphasizes an achievement, or background music matches to the intensity of game levels.

We return to the initial question: How and when does gamification work, and how and when not? Gamification is past the first wave of research, where fundamental questions of "what is gamification?" and "why does gamification work?" have been asked and substantially investigated. We contribute to the current wave by analyzing how and when sensory stimuli in gamified systems influence users' behaviors. These questions are posed, but far from answered. In addition, our study yields a new question: Where does gamification fit in which context? We use gamification on the road (addressing the question of "where?") and in an eco-driving context (the "which?"). The competing activity between the gamified system and the main task of driving shows the importance to address where gamification works and in which context. While our results and findings can be generalized in an eco-driving context, care must be taken in any effort to generalize the findings beyond the context of eco-driving due to distinct competing activities depending on the gamification design choices and the main task of the instrumental outcome. We discussed other contexts including gamification in education and fitness, which reveals boundaries of generalization and therefore addresses the question of "how and when not". What works effectively in one context, might be ineffective in a different context. We showed that variations of sensory stimuli play an important role in the task scenario. Due to these boundaries, we expect an increase of gamification research addressing implications of design choices and user–system interactions from an instrumental task context perspective.

CRediT authorship contribution statement

Kenan Degirmenci: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Michael H. Breitner:** Conceptualization, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Table A1
Survey instrument.

Construct	Item	Source
Perceived usefulness (PU)	PU1: The app helps me to adjust my acceleration and braking behaviour more quickly and more easily. PU2: The app helps me to improve my acceleration and braking behaviour. PU3: By using the app, I am better informed about my acceleration and braking behaviour. PU4: By using the app, I can decide more quickly and more easily whether I want to adjust my acceleration and braking behaviour or not. PU5: By using the app, I can better decide whether I want to adjust my acceleration and braking behaviour or not.	van der Heijden (2004)
Perceived ease of use (PEOU)	PEOU1: My interaction with the app is clear and understandable. PEOU2: Interacting with the app does not require a lot of mental effort. PEOU3: I find the app to be easy to use. PEOU4: I find it easy to get the app to do what I want it to do.	Venkatesh and Davis (2000)
Perceived enjoyment (PE)	Using the app is… PE1: disgusting–enjoyable PE2: dull–exciting PE3: unpleasant–pleasant PE4: boring–interesting	Cheung et al. (2000)
Intention to use (INT)	INT1: Given the chance, I intend to use the app. INT2: Given the chance, I predict that I should use the app in the future. INT3: It is likely that I will use the app in the near future.	Pavlou (2003)

Table A2
Demographics of participants.

	Control group (n = 22)		Visual-only group (n = 20)		Visual-auditory group (n = 21)		All participants (n = 63)	
Gender								
Male	18	81.8 %	14	70.0 %	16	76.2 %	48	72.2 %
Female	2	9.1 %	5	25.0 %	4	19.0 %	11	22.2 %
Not specified	2	9.1 %	1	5.0 %	1	4.8 %	4	5.6 %
Age								
18–19	5	22.7 %	6	30.0 %	4	19.0 %	15	23.8 %
20–29	11	50.0 %	13	65.0 %	17	81.0 %	41	65.1 %
30–39	5	22.7 %	0	0.0 %	0	0.0 %	5	7.9 %
≥40	0	0.0 %	1	5.0 %	0	0.0 %	1	1.6 %
Not specified	1	4.5 %	0	0.0 %	0	0.0 %	1	1.6 %
Profession								
Student	16	72.7 %	18	90.0 %	19	90.5 %	53	84.1 %
Employed	4	18.2 %	2	10.0 %	1	4.8 %	7	11.1 %
Not specified	2	9.0 %	0	0.0 %	1	4.8 %	3	4.8 %

Data availability

Data will be made available on request.

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Appendix

(See Tables A1-A2).

References

Ajzen, I. (1985). From intentions to actions: A theory of planned behavior. In J. Kuhl, & J. Beckmann (Eds.), *Action control: From cognition to behavior* (pp. 11–39). Berlin: Springer.

Ajzen, I., & Fishbein, M. (1980). *Understanding attitudes and predicting social behavior*. Upper Saddle River, NJ: Prentice-Hall.

Akhlaq, M., Sheltami, T. R., Helgeson, B., & Shakshuki, E. M. (2012). Designing an integrated driver assistance system using image sensors. *Journal of Intelligent Manufacturing, 23*(6), 2109–2132. https://doi.org/10.1007/s10845-011-0618-1

Al-Wreikat, Y., Serrano, C., & Sodré, J. R. (2021). Driving behaviour and trip condition effects on the energy consumption of an electric vehicle under real-world driving. *Applied Energy, 297*, 1–8. https://doi.org/10.1016/j.apenergy.2021.117096

Althuizen, N. (2018). Using structural technology acceptance models to segment intended users of a new technology: Propositions and an empirical illustration. *Information Systems Journal, 28*(5), 879–904. https://doi.org/10.1111/isj.12172

Ambrey, C. L., & Yen, B. T. H. (2018). How perceptions influence young drivers' intentions to participate in gamified schemes. *Transportation Research Part F: Traffic Psychology and Behaviour, 58*, 708–718. https://doi.org/10.1016/j.trf.2018.06.047

Aparicio, M., Oliveira, T., Bacao, F., & Painho, M. (2019). Gamification: A key determinant of massive open online course (MOOC) success. *Information & Management, 56*(1), 39–54. https://doi.org/10.1016/j.im.2018.06.003

Apple. (2014). Smooth Driver. Retrieved from https://itunes.apple.com/us/app/smooth-driver/id736543906.

Baddeley, A. D., & Hitch, G. (1974). Working memory. *The Psychology of Learning and Motivation: Advances in Research and Theory, 8*, 47–89. https://doi.org/10.1016/S0079-7421(08)60452-1

Baptista, G., & Oliveira, T. (2019). Gamification and serious games: A literature meta-analysis and integrative model. *Computers in Human Behavior, 92*, 306–315. https://doi.org/10.1016/j.chb.2018.11.030

Barla, P., Gilbert-Gonthier, M., Lopez Castro, M. A., & Miranda-Moreno, L. (2017). Eco-driving training and fuel consumption: Impact, heterogeneity and sustainability. *Energy Economics, 62*, 187–194. https://doi.org/10.1016/j.eneco.2016.12.018

Baroudi, J. J., & Orlikowski, W. J. (1989). The problem of statistical power in MIS research. *MIS Quarterly, 13*(1), 87–106. https://doi.org/10.2307/248704

Behl, A., & Dutta, P. (2020). Engaging donors on crowdfunding platform in disaster relief operations (DRO) using gamification: A civic voluntary model (CVM) approach. *International Journal of Information Management, 54*, 1–15. https://doi.org/10.1016/j.ijinfomgt.2020.102140

Birrell, S., Young, M. S., & Weldon, A. M. (2013). Vibrotactile pedals: Provision of haptic feedback to support economical driving. *Ergonomics, 56*(2), 282–292. https://doi.org/10.1080/00140139.2012.760750

Blohm, I., & Leimeister, J. M. (2013). Gamification: Design of IT-based enhancing services for motivational support and behavioral change. *Business & Information Systems Engineering, 5*(4), 275–278. https://doi.org/10.1007/s12599-013-0273-5

Bordens, K. S., & Abbott, B. B. (2018). *Research design and methods: A process approach* (10th ed.). New York: McGraw-Hill.

Bui, A., Veit, D., & Webster, J. (2015). *Gamification – a novel phenomenon or a new wrapping for existing concepts?* Paper presented at the International Conference on Information Systems, Fort Worth, TX.

Burke, B. (2013). The gamification of business. Retrieved from https://www.forbes.com/sites/gartnergroup/2013/01/21/the-gamification-of-business.

Cheung, W., Chang, M. K., & Lai, V. S. (2000). Prediction of Internet and World Wide Web usage at work: A test of an extended Triandis model. *Decision Support Systems, 30*(1), 83–100. https://doi.org/10.1016/S0167-9236(00)00125-1

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112*(1), 155–159. https://psycnet.apa.org/doi/10.1037/0033-2909.112.1.155.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319–340. https://doi.org/10.2307/249008

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management Science, 35*(8), 982–1003. https://doi.org/10.1287/mnsc.35.8.982

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1992). Extrinsic and intrinsic motivation to use computers in the workplace. *Journal of Applied Social Psychology, 22*(14), 1111–1132. https://doi.org/10.1111/j.1559-1816.1992.tb00945.x

De Vlieger, I., De Keukeleere, D., & Kretzschmar, J. G. (2000). Environmental effects of driving behaviour and congestion related to passenger cars. *Atmospheric Environment, 34*(27), 4649–4655. https://doi.org/10.1016/S1352-2310(00)00217-X

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). *From game design elements to gamefulness: Defining 'gamification'*. Paper presented at the International Academic MindTrek Conference: Envisioning Future Media Environments, Tampere, Finland.

Degirmenci, K., & Breitner, M. H. (2017). Consumer purchase intentions for electric vehicles: Is green more important than price and range? *Transportation Research Part D: Transport and Environment, 51*, 250–260. https://doi.org/10.1016/j.trd.2017.01.001

Degirmenci, K., Katolla, T. M., & Breitner, M. H. (2015). How can mobile applications reduce energy consumption? An experimental investigation of electric vehicles. *Paper presented at the European Conference on Information Systems, Münster, Germany*.

Diefenbach, S., & Müssig, A. (2019). Counterproductive effects of gamification: An analysis on the example of the gamified task manager Habitica. *International Journal of Human-Computer Studies, 127*, 190–210. https://doi.org/10.1016/j.ijhcs.2018.09.004

Diewald, S., Möller, A., Roalter, L., Stockinger, T., & Kranz, M. (2013). *Gameful design in the automotive domain – review, outlook and challenges*. Paper presented at the International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI 2013), Eindhoven, Netherlands.

Dissanayake, I., Mehta, N., Palvia, P., Taras, V., & Amoako-Gyampah, K. (2019). Competition matters! Self-efficacy, effort, and performance in crowdsourcing teams. *Information & Management, 1–12*. https://doi.org/10.1016/j.im.2019.04.001

Dogan, E., Bolderdijk, J. W., & Steg, L. (2014). Making small numbers count: Environmental and financial feedback in promoting eco-driving behaviours. *Journal of Consumer Policy, 37*, 413–422. https://doi.org/10.1007/s10603-014-9259-z

Donkers, A., Yang, D., & Viktorović, M. (2020). Influence of driving style, infrastructure, weather and traffic on electric vehicle performance. *Transportation Research Part D: Transport and Environment, 88*, 1–13. https://doi.org/10.1016/j.trd.2020.102569

Elliot, S., & Webster, J. (2017). Editorial: Special issue on empirical research on information systems addressing the challenges of environmental sustainability: An imperative for urgent action. *Information Systems Journal, 27*(4), 367–378. https://doi.org/10.1111/isj.12150

Enríquez, F., Troyano, J. A., & Romero-Moreno, L. M. (2019). Using a business process management system to model dynamic teaching methods. *Journal of Strategic Information Systems, 28*(3), 275–291. https://doi.org/10.1016/j.jsis.2018.07.002

Fang, Y., Ma, Y., Mo, D., Zhang, S., Xiang, M., & Zhang, Z. (2019). Methodology of an exercise intervention program using social incentives and gamification for obese children. *BMC Public Health, 1–10*. https://doi.org/10.1186/s12889-019-6992-x

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41*(4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Fonseca, N., Casanova, J., & Espinosa, F. (2010). *Influence of driving style on fuel consumption and emissions in diesel powered passenger car*. Dübendorf, Switzerland: Paper presented at the International Symposium Transport and Air Pollution.

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research, 18*(1), 39–50. https://doi.org/10.1177/002224378101800104

Fors, C., Kircher, K., & Ahlström, C. (2015). Interface design of eco-driving support systems – truck drivers' preferences and behavioural compliance. *Transportation Research Part C: Emerging Technologies, 58*(Part D), 706–720. https://doi.org/10.1016/j.trc.2015.03.035

Gamma, K., Mai, R., Cometta, C., & Loock, M. (2021). Engaging customers in demand response programs: The role of reward and punishment in customer adoption in Switzerland. *Energy Research & Social Science, 74*, 1–16. https://doi.org/10.1016/j.erss.2021.101927

Gholami, R., Watson, R. T., Hasan, H., Molla, A., & Bjørn-Andersen, N. (2016). Information systems solutions for environmental sustainability: How can we do more? *Journal of the Association for Information Systems, 17*(8), 521–536. https://doi.org/10.17705/1jais.00435.

Groening, C., & Binnewies, C. (2019). "Achievement unlocked!" - the impact of digital achievements as a gamification element on motivation and performance. *Computers in Human Behavior, 2019*, 151–166. https://doi.org/10.1016/j.chb.2019.02.026

Günther, M., Kacperski, C., & Krems, J. F. (2020). Can electric vehicle drivers be persuaded to eco-drive? A field study of feedback, gamification and financial rewards in Germany. *Energy Research & Social Science, 63*, 1–9. https://doi.org/10.1016/j.erss.2019.101407

Hair, J. F., Jr., Black, W. C., Babin, B. J., & Anderson, R. E. (2019). *Multivariate data analysis* (8th ed.). Andover, Hampshire: Cengage.

Hamari, J. (2017). Do badges increase user activity? A field experiment on the effects of gamification. *Computers in Human Behavior, 71*, 469–478. https://doi.org/10.1016/j.chb.2015.03.036

Hamari, J., & Koivisto, J. (2015). Why do people use gamification services? *International Journal of Information Management, 35*(4), 419–431. https://doi.org/10.1016/j.ijinfomgt.2015.04.006

Hammedi, W., Leclercq, T., Poncin, I., & Alkire, L. (2021). Uncovering the dark side of gamification at work: Impacts on engagement and well-being. *Journal of Business Research, 122*, 256–269. https://doi.org/10.1016/j.jbusres.2020.08.032

Hammerschmidt, J., & Hermann, T. (2017). EcoSonic: Auditory peripheral monitoring of fuel consumption for fuel-efficient driving. *Displays, 47*, 40–50. https://doi.org/10.1016/j.displa.2016.11.002

Helmbrecht, M., Monreal, C. O., & Bengler, K. (2014). How electric vehicles affect driving behavioral patterns. *IEEE Intelligent Transportation Systems Magazine, 6*(3), 22–32. https://doi.org/10.1109/MITS.2014.2315758

Henfridsson, O., & Lind, M. (2014). Information systems strategizing, organizational sub-communities, and the emergence of a sustainability strategy. *Journal of Strategic Information Systems, 23*(1), 11–28. https://doi.org/10.1016/j.jsis.2013.11.001

Hermsen, S., Frost, J., Renes, R. J., & Kerkhof, P. (2016). Using feedback through digital technology to disrupt and change habitual behavior: A critical review of current literature. *Computers in Human Behavior, 57*, 61–74. https://doi.org/10.1016/j.chb.2015.12.023

Höllig, C. E., Tumasjan, A., & Welpe, I. M. (2020). Individualizing gamified systems: The role of trait competitiveness and leaderboard design. *Journal of Business Research, 106*, 288–303. https://doi.org/10.1016/j.jbusres.2018.10.046

Hu, K., Wu, J., & Schwanen, T. (2017). Differences in energy consumption in electric vehicles: An exploratory real-world study in Beijing. *Journal of Advanced Transportation, 1–17*. https://doi.org/10.1155/2017/4695975

International Energy Agency. (2018). CO_2 emissions from fuel combustion. Retrieved from https://webstore.iea.org/co2-emissions-from-fuel-combustion-2018.

Jamson, S. L., Brouwer, R., & Seewald, P. (2015). Supporting eco-driving. *Transportation Research Part C: Emerging Technologies, 58*(Part D), 629–630. https://doi.org/10.1016/j.trc.2015.06.020

Kankanhalli, A., Taher, M., Cavusoglu, H., & Kim, S. H. (2012). *Gamification: A new paradigm for online user engagement*. Orlando, FL: Information Systems.

Kircher, K., Fors, C., & Ahlstrom, C. (2014). Continuous versus intermittent presentation of visual eco-driving advice. *Transportation Research Part F: Traffic Psychology and Behaviour, 24*, 27–38. https://doi.org/10.1016/j.trf.2014.02.007

Knowles, M., Scott, H., & Baglee, D. (2012). The effect of driving style on electric vehicle performance, economy and perception. *International Journal of Electric and Hybrid Vehicles, 4*(3), 228–247. https://doi.org/10.1504/IJEHV.2012.050492

Koivisto, J., & Hamari, J. (2019). The rise of motivational information systems: A review of gamification research. *International Journal of Information Management, 45*, 191–210. https://doi.org/10.1016/j.ijinfomgt.2018.10.013

Landers, R. N. (2019). Gamification misunderstood: How badly executed and rhetorical gamification obscures its transformative potential. *Journal of Management Inquiry, 28*(2), 137–140.

Landers, R. N., Auer, E. M., & Abraham, J. D. (2020). Gamifying a situational judgment test with immersion and control game elements. *Journal of Managerial Psychology, 1–15*. https://doi.org/10.1108/JMP-10-2018-0446

Landers, R. N., Bauer, K. N., & Callan, R. C. (2017). Gamification of task performance with leaderboards: A goal setting experiment. *Computers in Human Behavior, 71*, 508–515. https://doi.org/10.1016/j.chb.2015.08.008

Lieberoth, A., Jensen, N. H., & Bredahl, T. (2018). Selective psychological effects of nudging, gamification and rational information in converting commuters from cars to buses: A controlled field experiment. *Transportation Research Part F: Traffic Psychology and Behaviour, 55*, 246–261. https://doi.org/10.1016/j.trf.2018.02.016

Liu, D., Santhanam, R., & Webster, J. (2017). Toward meaningful engagement: A framework for design and research of gamified information systems. *MIS Quarterly, 41*(4), 1011–1034. https://doi.org/10.25300/MISQ/2017/41.4.01.

Lv, C., Zhang, J., Li, Y., & Yuan, Y. (2015). Mechanism analysis and evaluation methodology of regenerative braking contribution to energy efficiency improvement of electrified vehicles. *Energy Conversion and Management, 92*, 469–482. https://doi.org/10.1016/j.enconman.2014.12.092

Mayer, R. E. (2009). *Multimedia learning* (2nd ed.). Cambridge, UK: Cambridge University Press.

McConky, K., Chen, R. B., & Gavi, G. R. (2018). A comparison of motivational and informational contexts for improving eco-driving performance. *Transportation Research Part F: Traffic Psychology and Behaviour, 52*, 62–74. https://doi.org/10.1016/j.trf.2017.11.013

Meschtscherjakov, A., Wilfinger, D., & Scherndl, T., Tscheligi, Manfred. (2009). *Acceptance of future persuasive in-car interfaces towards a more economic driving behaviour*. Paper presented at the International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI 2009), Essen, Germany.

Moro, S., Ramos, P., Esmerado, J., & Jalali, S. M. J. (2019). Can we trace back hotel online reviews' characteristics using gamification features? *International Journal of Information Management, 44*, 88–95. https://doi.org/10.1016/j.ijinfomgt.2018.09.015

Morschheuser, B., Hamari, J., & Maedche, A. (2019). Cooperation or competition – when do people contribute more? A field experiment on gamification of crowdsourcing. *International Journal of Human-Computer Studies, 127*, 7–24. https://doi.org/10.1016/j.ijhcs.2018.10.001

Morschheuser, B., Hassan, L., Werder, K., & Hamari, J. (2018). How to design gamification? A method for engineering gamified software. *Information and Software Technology, 95*, 219–237. https://doi.org/10.1016/j.infsof.2017.10.015

Mulcahy, R., Russell-Bennett, R., & Iacobucci, D. (2020). Designing gamified apps for sustainable consumption: A field study. *Journal of Business Research, 106*, 377–387. https://doi.org/10.1016/j.jbusres.2018.10.026

Nacke, L. E., & Deterding, S. (2017). The maturing of gamification research. *Computers in Human Behavior, 71*, 450–454. https://doi.org/10.1016/j.chb.2016.11.062

Nacke, L. E., Grimshaw, M. N., & Lindley, C. A. (2010). More than a feeling: Measurement of sonic user experience and psychophysiology in a first-person shooter game. *Interacting with Computers, 22*(5), 336–343. https://doi.org/10.1016/j.intcom.2010.04.005

Nandhakumar, J., Panourgias, N. S., & Scarbrough, H. (2013). From knowing it to 'getting it': Envisioning practices in computer games development. *Information Systems Research, 24*(4), 933–955. https://doi.org/10.1287/isre.2013.0482

Née, M., Contrand, B., Orriols, L., Gil-Jardiné, C., Galéra, C., & Lagarde, E. (2019). Road safety and distraction, results from a responsibility case-control study among a sample of road users interviewed at the emergency room. *Accident Analysis and Prevention, 122*, 19–24. https://doi.org/10.1016/j.aap.2018.09.032

Nousias, S., Tselios, C., Bitzas, D., Amaxilatis, D., Montesa, J., Lalos, A. S., … Chatzigiannakis, I. (2019). Exploiting gamification to improve eco-driving behaviour: The GamECAR approach. *Electronic Notes in Theoretical Computer Science, 343*, 103–116. https://doi.org/10.1016/j.entcs.2019.04.013

Orfila, O., Saint Pierre, G., & Messias, M. (2015). An android based ecodriving assistance system to improve safety and efficiency of internal combustion engine passenger cars. *Transportation Research Part C: Emerging Technologies, 58*, 772–782. https://doi.org/10.1016/j.trc.2015.04.026

Oviedo-Trespalacios, O., Briant, O., Kaye, S.-A., & King, M. (2020). Assessing driver acceptance of technology that reduces mobile phone use while driving: The case of mobile phone applications. *Accident Analysis and Prevention, 135*, 1–9. https://doi.org/10.1016/j.aap.2019.105348

Oviedo-Trespalacios, O., Haque, M. M., King, M., & Washington, S. (2016). Understanding the impacts of mobile phone distraction on driving performance: A systematic review. *Transportation Research Part C: Emerging Technologies, 72*, 360–380. https://doi.org/10.1016/j.trc.2016.10.006

Parsons, A., & Conroy, D. (2006). Sensory stimuli and e-tailers. *Journal of Consumer Behaviour, 5*(1), 69–81. https://doi.org/10.1002/cb.32

Pavlou, P. A. (2003). Consumer acceptance of electronic commerce: Integrating trust and risk with the technology acceptance model. *International Journal of Electronic Commerce, 7*(3), 101–134. https://doi.org/10.1080/10864415.2003.11044275

Pietra, A., Vazquez Rull, M., Etzi, R., Gallace, A., Scurati, G. W., Ferrise, F., & Bordegoni, M. (2021). Promoting eco-driving behavior through multisensory stimulation: A preliminary study on the use of visual and haptic feedback in a virtual reality driving simulator. *Virtual Reality, 1–15*. https://doi.org/10.1007/s10055-021-00499-1

Putz, L.-M., Hofbauer, F., & Treiblmaier, H. (2020). Can gamification help to improve education? Findings from a longitudinal study. *Computers in Human Behavior, 110*, 1–12. https://doi.org/10.1016/j.chb.2020.106392

Qin, L., Li, Z. R., Chen, Z., Bill, M. S. A., & Noyce, D. A. (2019). Understanding driver distractions in fatal crashes: An exploratory empirical analysis. *Journal of Safety Research, 69*, 23–31. https://doi.org/10.1016/j.jsr.2019.01.004

Qiu, C., & Wang, G. (2016). New evaluation methodology of regenerative braking contribution to energy efficiency improvement of electric vehicles. *Energy Conversion and Management, 119*, 389–398. https://doi.org/10.1016/j.enconman.2016.04.044

Rapp, A. (2017). Designing interactive systems through a game lens: An ethnographic approach. *Computers in Human Behavior, 71*, 455–468. https://doi.org/10.1016/j.chb.2015.02.048

Rapp, A., Hopfgartner, F., Hamari, J., Linehan, C., & Cena, F. (2019). Strengthening gamification studies: Current trends and future opportunities of gamification research. *International Journal of Human-Computer Studies, 127*, 1–6. https://doi.org/10.1016/j.ijhcs.2018.11.007

Rapp, A., Tirassa, M., & Tirabeni, L. (2019). Rethinking technologies for behavior change: A view from the inside of human change. *ACM Transactions on Computer-Human Interaction, 26*(4), 1–33. https://doi.org/10.1145/3318142

Regan, M. A., Hallett, C., & Gordon, C. P. (2011). Driver distraction and driver inattention: Definition, relationship and taxonomy. *Accident Analysis and Prevention, 43*(5), 1771–1781. https://doi.org/10.1016/j.aap.2011.04.008

Rouzikhah, H., King, M., & Rakotonirainy, A. (2013). Examining the effects of an eco-driving message on driver distraction. *Accident Analysis and Prevention, 50*, 975–983. https://doi.org/10.1016/j.aap.2012.07.024

Sanguinetti, A., Queen, E., Yee, C., & Akanesuvan, K. (2020). Average impact and important features of onboard eco-driving feedback: A meta-analysis. *Transportation Research Part F: Traffic Psychology and Behaviour, 70*, 1–14. https://doi.org/10.1016/j.trf.2020.02.010

Santhanam, R., Liu, D., & Shen, W.-C.-M. (2016). Gamification of technology-mediated training: Not all competitions are the same. *Information Systems Research, 27*(2), 453–465. https://doi.org/10.1287/isre.2016.0630

Schell, J. (2008). *The art of game design: A book of lenses*. Burlington, MA: Morgan Kaufmann.

Seaborn, K., & Fels, D. I. (2015). Gamification in theory and action: A survey. *International Journal of Human-Computer Studies, 74*, 14–31. https://doi.org/10.1016/j.ijhcs.2014.09.006

Seidel, S., Berente, N., Martinez, B., Lindberg, A., Lyytinen, K., & Nickerson, J. V. (2018). Autonomous tools in system design: Reflective practice in ubisoft's *ghost recon wildlands* project. *Computer, 51*(10), 16–23. https://doi.org/10.1109/MC.2018.3971341

Shevchuk, N., Degirmenci, K., & Oinas-Kukkonen, H. (2019). Adoption of gamified persuasive systems to encourage sustainable behaviors: Interplay between perceived persuasiveness and cognitive absorption. *Paper presented at the International Conference on Information Systems, Munich, Germany*.

Sivak, M., & Schoettle, B. (2012). Eco-driving: Strategic, tactical, and operational decisions of the driver that influence vehicle fuel economy. *Transport Policy, 22*, 96–99. https://doi.org/10.1016/j.tranpol.2012.05.010

Steinberger, F., Schroeter, R., Foth, M., & Johnson, D. (2017). *Designing gamified applications that make safe driving more engaging*. Paper presented at the Conference on Human Factors in Computing Systems, Denver, CO.

Stillwater, T., & Kurani, K. S. (2013). Drivers discuss ecodriving feedback: Goal setting, framing, and anchoring motivate new behaviors. *Transportation Research Part F: Traffic Psychology and Behaviour, 19*, 85–96. https://doi.org/10.1016/j.trf.2013.03.007

Suh, A., Cheung, C. M. K., Ahuja, M., & Wagner, C. (2017). Gamification in the workplace: The central role of the aesthetic experience. *Journal of Management Information Systems, 34*(1), 268–305. https://doi.org/10.1080/07421222.2017.1297642

Tulusan, J., Steggers, H., Staake, T., & Fleisch, E. (2012). Supporting eco-driving with eco-feedback technologies: Recommendations targeted at improving corporate car drivers' intrinsic motivation to drive more sustainable. *Sprouts: Working Papers on. Information Systems, 12*(3), 1–18.

Vaezipour, A., Rakotonirainy, A., Haworth, N., & Delhomme, P. (2017). Enhancing eco-safe driving behavior through the use of in-vehicle human-machine interface: A qualitative study. *Transportation Research Part A: Policy and Practice, 100*, 247–263. https://doi.org/10.1016/j.tra.2017.04.030

van der Heijden, H. (2004). User acceptance of hedonic information systems. *MIS Quarterly, 28*(4), 695–704. https://doi.org/10.2307/25148660

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science, 46*(2), 186–204. https://doi.org/10.1287/mnsc.46.2.186.11926

Watson, R. T., Corbett, J., Boudreau, M.-C., & Webster, J. (2012). An information strategy for environmental sustainability. *Communications of the ACM, 55*(7), 28–30. https://doi.org/10.1145/2209249.2209261

Xie, J. Y., Chen, H.-Y.-W., & Donmez, B. (2016). *Gaming to safety: Exploring feedback gamification for mitigating driver distraction*. Washington, DC: Paper presented at the Human Factors and Ergonomics Society Annual Meeting.

Zavalko, A. (2018). Applying energy approach in the evaluation of eco-driving skill and eco-driving training of truck drivers. *Transportation Research Part D: Transport and Environment, 62*, 672–684. https://doi.org/10.1016/j.trd.2018.01.023

Zichermann, G., & Cunningham, C. (2011). *Gamification by design: Implementing game mechanics in web and mobile apps*. Sebastopol, CA: O'Reilly Media.