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van Gent, P.; Farah, H.; Nes, Nicole Van; van Arem, B.

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The Persuasive Automobile: Design and Evaluation of a Persuasive Lane-Specific Advice Human Machine Interface

PAUL VAN GENT[1], HANEEN FARAH[1], NICOLE VAN NES[2], AND BART VAN AREM[1] (Senior Member, IEEE)

[1]Transport and Planning Department, Delft University of Technology, 2628 CN Delft, The Netherlands

[2]Department of Human Factors in Vehicle Automation, Dutch Road Safety Research Institute (SWOV), 2594 AW Hague, The Netherlands

CORRESPONDING AUTHOR: P. VAN GENT (e-mail: p.vangent@tudelft.nl)

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ABSTRACT Traffic congestion is a major societal challenge. By advising drivers on the optimal lane to drive, traffic flow can be improved, and congestion reduced. In this paper we describe the development of a lane-specific advice Human Machine Interface (HMI). Persuading drivers to follow an advice that is beneficial to the traffic situation, but may not be immediately beneficial to the drivers themselves, is challenging. In this paper we define persuasive elements to encourage drivers to follow the lane-specific advices. We then describe the interface design process, followed by its evaluation using a driving simulator study. In the simulator study, the effect of two types of persuasion are evaluated: a competitive variant where drivers could earn points and compete with others, and a cooperative variant where real-time information on the number of compliant drivers was available. Participants drove in the simulator on two days. Between days, the treatment groups viewed a Web-portal showing their performance and encouragement from an avatar. Those in the competitive and cooperative groups followed significantly more advices (117 and 111) than those in the control group (89). No significant differences were visible between competitive and cooperative groups. The differences between groups only emerged on the second day.

INDEX TERMS Driving simulator, human factors, human machine interface, intelligent vehicles, persuasive technology.

I. INTRODUCTION

A. BACKGROUND

THE EFFECTS of congestion on both the economy and individuals are large. Aside from annoyance and time loss, congestion is a source of higher emissions [1] and negatively impacts safety. The benefits of reducing congestion are obviously large. Driver-assistance systems that can help reduce congestion and improve flow are for example connected cruise control [2], or a congestion assistant [3] which, based on simulation experiments, would reduce travel-time delay by 30% even at a 10% penetration rate.

Recent technological advancements add to the possibilities by enabling vehicles to detect the specific lane they are driving on based on low-cost precise point positioning GPS receivers [4], [5]. This makes traffic control on the individual level possible by advising drivers on a specific lane they can take [6], [7]. Such an advice system needs to be safe as well as persuasive, in order for it to be successful [8]. The next question then becomes how to make such a system persuasive and safe. To determine this, we investigate and describe the development of a persuasive lane-specific advice Human Machine Interface (HMI) in this paper.

The rest of Section I introduces the literature background for the study. Section II reports the methods and results of two questionnaire studies that were performed to determine the type of auditory chime used to alert the driver to an advice, the location of the interface, and whether to provide context for the advice (reason for advice and feedback on behaviour). In Section III we develop the persuasive advices and a Web-portal for the simulator study based on the results of the questionnaire studies from Section II. Section IV describes the methods used in the simulator study to evaluate the effectiveness of the persuasive lane change advice. Section V describes the results of the simulator study, and in Sections VI and VII the results are discussed, and conclusions drawn.

B. OBJECTIVES

We are working on an in-car system with the goal of reducing congestion through lane-specific advices. This will be achieved by stimulating a better distribution of traffic over the available lanes on a multi-lane highway through lane-specific advices. The challenge is to persuade drivers to follow non-compulsory advices that are in the benefit of all drivers on a given road segment, but not necessarily in the benefit of individual drivers [9]. Some drivers may, for example, be asked to move to a slower lane in order to maintain a balanced traffic system.

The main objective of this study is to find a way to persuade drivers to comply with these voluntary lane-specific advice messages, using methods from the field of persuasive technology [8], [10], [11]. To achieve this, we develop a multimodal (auditory, visual) interface to convey lane-specific requests to the driver. This leads to the following sub-goals: to design an auditory and visual signal, to determine whether to provide context for the advice to the driver (reason for advice, feedback on behaviour), and to define the safest location for the interface. This paper describes the design process of the interface in two iterative steps, and the evaluation of the lane-specific advice HMI's effects in a driving simulator.

C. TECHNIQUES FOR DRIVER PERSUASION

Our aim is to stimulate drivers to follow lane-specific advice messages, without enforcing compliance. Gamification has been used to change behaviour in people [12]. Video games are designed to create environments that motivate people to display certain behaviours over others, often to win the game. Gamification is about applying those game design elements that elicit different behaviour patterns to non-game contexts [13]. Such elements include challenges, leader boards and achievements [12]. In driving contexts gamification has been used for example to encourage eco-driving behaviour [14]–[16], and to encourage safer driving behaviour [17], [18]. Other ways of achieving behavioural change include methods from persuasive technology [10], [19] and behavioural economics [20]–[22].

The different approaches are unified in the Persuasive Systems Design (PSD) model, which takes concepts from the different persuasive fields and brings them together into a single model [23], [24]. The PSD specifies that a system can be made more persuasive by offering support to the user in various categories: primary task support, dialogue support, system credibility support and social support [8], [23].

Persuading different people in different situations might require different approaches, and there are indications that not every person is equally susceptible to being persuaded, at least from studies on health-based persuasive applications [25] and gaming settings [26], [27]. This provides a challenge because we need to maximise persuasive potential while not creating a personalised solution for every driver, which would needlessly complicate the design. Orji *et al.* [26] provide a possible solution. The authors investigated persuasive effectiveness on a range of 'gamer personalities' in 1.108 gamers. The personality types they used were derived from a neurobiological study into gamer personalities called BrainHEX [28]. The personality types found (seeker, survivor, daredevil, mastermind, conqueror, socialiser, achiever) had, as expected, stronger relations with gaming and cannot readily be translated to the driving environment. However, a set of persuasive techniques were found that worked well across all the different personality types. These are competition and comparison, which fit in the "social support" component from the PSD model [23]. Self-monitoring and suggestion, respectively from "dialogue support" and "primary task support" in the PSD, were found to be effective across the different personality types. Interestingly, praise and rewards did not have a strong effect in this study, contrary to what others have reported. This may be in line with what is reported by [29], where the effectiveness of feedback combined especially with emotionally expressive avatars did not always work well, especially when negative emotions on avatars were combined with negative text messages.

D. DEFINING MESSAGE MODALITY

Aside from persuading a driver, the modality that is used to convey any type of information to a driver is of major importance, as humans have limited information processing capacity. Dangerous and even life-threatening situations may occur when overloading a driver [30]–[32], or when distracting a driver with an advice at the wrong moment [33], [34].

Visual interfaces have the advantage of having high information bandwidth and being self-paced. However, many visual interfaces require the driver to take their eyes off the road. Taking eyes off the road has been shown to have serious consequences for lane-keeping ability [35], and may cause drivers to miss safety-critical events on the road.

Heads-Up Displays (HUD) have been put forward as a means of reducing the negative aspects of visual displays in cars. However, HUDs have some problems as well related to both psychological and biological processes. The 'looked-but-failed-to-see' problem [36] is an example. This occurs when an object (like a pedestrian, cyclist, or other car) is within the field of view of a driver, but is not perceived. This seems to be a cognitive problem rather than a sensory one, where the object is visible on the retina but not consciously registered by the driver. HUDs might exacerbate this issue by adding an additional stimulus to the driver's field of view. In other words: even if the driver's eyes are on the road, that does not mean the driver's attention is on the road. In this regard it is important to keep visually presented information brief and easily understood, for example by making stimuli similar to their real-world counterparts. This reduces cognitive distance [37], which is defined as the ease of transforming digital information to a task at hand [38]. An example of an advice with a short cognitive distance is a lane change request that displays the current lane configuration, the ego vehicle on its current lane, and an arrow or instruction pointing to the lane to which the driver needs to move. This way the driver does not need to expend much cognitive processing on understanding the advice, but can instead focus on the requested behaviour.

Biological processes might also interfere with driving. For example, the eye has a so-called resting focus (or 'dark focus'), which is the focal distance of the eye when the iris is relaxed. Typically, this is between 0.5-2.0 meters. Stimuli placed in this distance can draw a particularly dominant accommodation response from the eye [39]. This was originally called the Mandelbaum effect and it is especially prevalent when visibility conditions are poor [40]. This might create issues with HUDs in certain weather conditions, which needs to be considered when designing an HMI for on-road use, for example by not having the HUD be always on, and to be sensitive to contexts by reducing its saliency when visibility conditions are poor.

Multimodal interfaces have been proposed to reduce the negative aspects of using a single modality, especially in complex environments [41]. From a theoretical perspective this works by reducing load on a single modality and allowing drivers to better spread work over their available mental resources [42]. Spreading information over multiple modalities has been shown to induce lower workloads [43] and better reaction times [44] in participants.

Based on these benefits for workload and reaction times, in this study we chose to design for a multimodal display, where the advice is visually presented and announced by an auditory chime. The chime is used to alert the driver whenever an advice is available, as described by for example [41]. This way the driver can focus on the road and only has to look at the display whenever an advice is available.

E. MAKING IT PERSONAL

Avatars are representations of a virtual character. They are more effective than textual information in eliciting a human-like interaction between system and driver [29]. Scott *et al.* showed that adding emotional expressions increased persuasive effectiveness and trustworthiness of a system. Avatars have been used in gamified driving contexts such as Driving Miss Daisy [17], which helps improve driving skills by providing a virtual passenger that occasionally comments on driving style. To facilitate more human communication, we developed an avatar based off a freely available clipart from www.clipartroo.com.

The avatar (Figure 1) had a happy and an unhappy state depending on how drivers would react to advices. We chose a stylized avatar, so it resembled a car rather than a human.

FIGURE 1. Design of the avatar, showing its happy state (left) and sad state (right).

The choice was based on work by Verberne *et al.* [45], who showed that trust in an in-car system improved if drivers perceived it as sharing their driving goals. By styling the avatar like a car that was happy when congestion was avoided, we aimed to visualize that the driver's goal of reaching a destination without congestion was shared by their car. This stylizing is unlikely to change participant's response to the avatar, as Bailenson *et al.* [46] for example demonstrated people tend to respond to avatars in a natural way as if they are human, even if they are highly stylized and don't resemble humans at all.

F. USING A DRIVING SIMULATOR FOR HMI RESEARCH

The driving simulator is a powerful tool to investigate human behaviour in a controlled setting where traffic and weather conditions can be standardised [47]. In the context of our study, a simulator offers an environment where our novel HMI design can be safely tested without the danger of distracting a participant in real traffic.

Wang *et al.* [48] have shown that medium fidelity driving simulators can be used effectively to evaluate in-vehicle information interfaces, which our proposed persuasive HMI is, although care must be taken to ensure no confounding variables are introduced [49].

II. DEVELOPING THE PERSUASIVE INTERFACE–TWO QUESTIONNAIRE STUDIES

Prior to performing our simulator experiment we needed to define several important aspects. These include the type of auditory alert used to announce the advice, the location of the advice, and whether to provide a reason for the advice or feedback on the performed behaviour. If the advice is unclear, the alert not salient enough, or if the system is considered annoying, it is unlikely drivers will follow advices or continue using the system [8], [50]. Two questionnaire studies were performed. The first questionnaire study is described in Section II-A and II-B, and investigates whether to precede the advice by an auditory chime, and if so, which chime. The second questionnaire is described in Section II-C and II-D. It uses the chime determined in the first questionnaire, and investigates where the advice should be located based on driver preferences (central console, HUD, or near speedometer), and whether to provide a reason for the given advice or feedback on driver behaviour.

A. DETERMINING THE AUDITORY ALERT CHIME–METHODS

To determine which auditory chime to use to alert drivers to an available advice, we performed a questionnaire study. The aim was to select a chime that sounded friendly (to not irritate the driver), could alert the driver, and that was not judged to be distracting.

A range of auditory alert chimes were designed using Apple's Logic Pro digital audio workstation, and the Omnipshere digital synthesizer. The chimes were designed around the C Major tonality, which has an open and warm character. 15 chime types were generated in total. Where applicable, variations in rhythm and variations in pitch were generated per chime type. This gave a total of 53 possible alert sounds. We reduced these possibilities by making a subjective pre-selection of seven auditory alerts.

The questionnaire was distributed through Google Forms. In the questionnaire participants were informed about the goals of our proposed lane-specific advice HMI, and subsequently presented with the seven selected auditory chimes. After each chime they were asked for their impression regarding the alert, specifically if it was: informative, intrusive, friendly, distracting, annoying, easy to miss, and urgent. Each item was rated on a 7-point scale, ranging from disagree completely (−3), to neutral (0), to agree completely (3). Participants were recruited by an advert on social media (LinkedIn, Twitter), and through a recruitment e-mail to several departments at Delft University of Technology.

B. DETERMINING THE AUDITORY ALERT TYPE–ANALYSIS AND RESULTS

20 participants took part in the auditory chime questionnaire. 7 participants were female, 13 male. All participants were frequent drivers. 14 participants indicated driving at most 1000 km per month, and the remaining 6 participants between 1000 and 2000 km per month. This range is close to the Dutch national average for private cars of 13.000 km on a yearly basis [51].

Questionnaire data were analysed using a principal component analysis (PCA), a method that transforms a set of observations into uncorrelated variables as described for example in [52]. This way we can find underlying constructs shared by different questions in a questionnaire.

The result of the PCA was visualised in a scree plot, which displayed a distinctive 'knee' at a two-component solution, which together explained 81.97% of all variance in the data set. The factor loadings for the two-component solution are displayed in table 1. We removed factor loadings smaller than 0.2.

The first component loads negatively on intrusiveness, distraction potential, annoyance and urgency, while loading positively on friendliness and being easy to miss. It seems to reflect a general 'likeability' of the chime. The chime being easy to miss is likely inversely related to its potential to be intrusive, distracting and annoying. The second component loads strongly negative on informativeness and on friendliness, while loading positively on being easy to miss and annoyance. This component seems to indicate that the alert is unclear: it is rated low on being informative, and high on being easy to miss and annoyance. It seems likely that an unclear message during driving would lead to annoyance.

TABLE 1. PCA loadings on first two components.

Label	Component 1	Component 2
Informative	-	-0.779
Intrusive	-0.423	-
Friendly	0.377	-0.297
Distracting	-0.341	-
Annoying	-0.507	0.278
Easy to miss	0.378	0.422
Urgent	-0.395	-

TABLE 2. Loadings of each chime on the two main PCA components.

Chime number	Component	Component 2
1	1.499	0.063
2	0.224	-0.194
3	-1.409	-0.060
4	-1.018	0.192
5	0.432	0.178
6	0.903	-0.058
7	-0.243	-0.017

The loadings of each of the seven chimes on the two components are displayed below in table 2.

We selected chime #1, which loads strongly on the first component ('likeability') and not on the second component ('unclear').

C. DETERMINING THE INTERFACE AND MESSAGE CHARACTERISTICS–METHODS

After choosing the alert chime, we needed to determine the driver preferences regarding the implementation details of the lane-specific advice HMI, thus a second questionnaire study was performed. The questionnaire consisted of three parts. Most questions were answered on the same seven-point scale as the previous questionnaire (−3 – completely disagree, 0 – neutral, 3 – completely agree).

In the first part of the questionnaire participants were presented with three videos (figure 2), each showing the same lane-specific advice but in a different location: central console (1), heads-up display (2), and on the speedometer (3). After viewing each video, participants answered on a 7-point scale whether they noticed the advice quickly, if it was distracting, if they were used to looking at the specific location, if they felt they had to take their eyes off the road too long, if they felt safe looking at the specific location, if the location was convenient, and if they thought they would miss the advice easily at this location.

In the second part participants were presented with a full screen video of the same advice (figure 3), but with included audio and haptic feedback. This section served to test responses to the selected audio chime from the previous

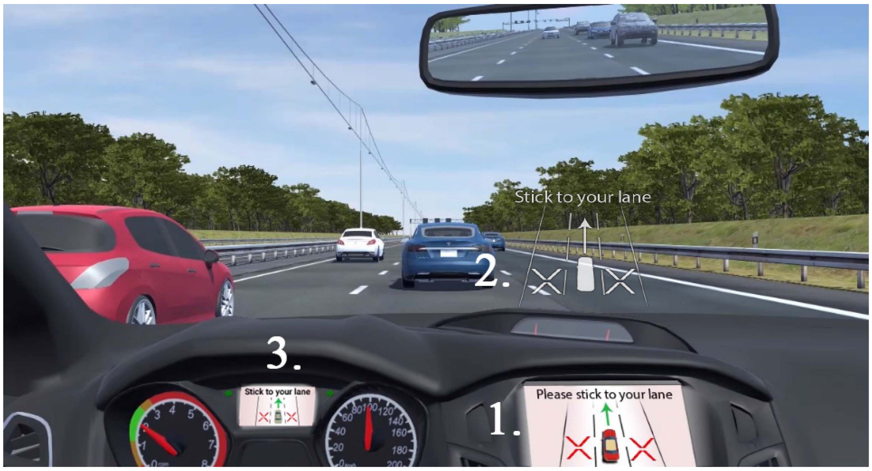

FIGURE 2. Screenshot from one of the three videos shown to participants. The video shows regular traffic on a typical Dutch highway, with the active advice shown on the central console (1), the HUD (2), and near speedometer displays (3).

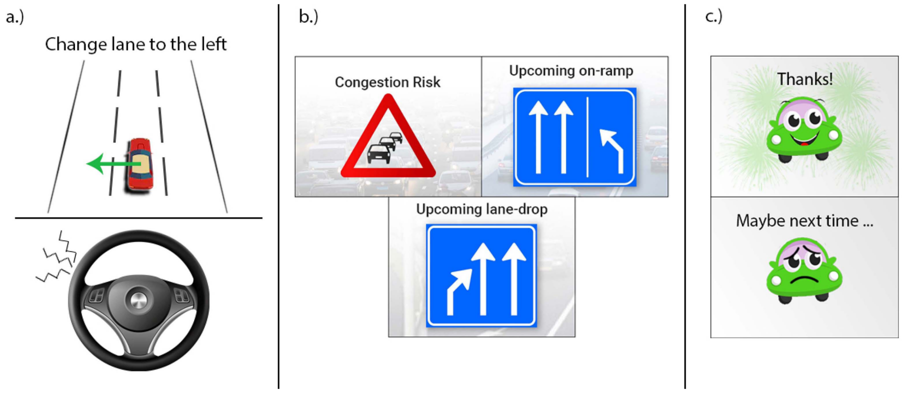

FIGURE 3. Haptic feedback was shown on the steering wheel a.), and an audio message was played through the corresponding stereo channel. Image b.) shows possible reasons for an advice. Image c.) shows the two avatar states.

questionnaire, and to test whether to include haptic feedback in the steering wheel as well. Since no actual steering wheel would be available while filling in the questionnaire, the haptic feedback was displayed on a steering wheel below the advice visualisation as shown in figure 3 a.) and accompanied by a vibration sound. If vibration occurred on a particular side of the steering wheel, the vibration audio was only played through the corresponding stereo channel.

The last section of the questionnaire examined the context needed for the advice, specifically whether to provide the reason for the advice and feedback on driver behaviour. We know from earlier research [50] that if drivers do not perceive the reason for an advice, they are less inclined to follow it. Providing feedback can also support the formation of habits which are a main factor in making persuasive effects last over time [53]. Participants were shown an example video of an advice preceded by a message displaying the reason for the advice (figure 3 b.), and a message after the advice displaying feedback about their behaviour that consisted of the avatar thanking them or encouraging them to do better next time (figure 3 c.)). After this, they answered several questions about how it would impact their understanding of the advice, their likelihood of following it, and their perceived safety.

D. DETERMINING THE INTERFACE AND MESSAGE CHARACTERISTICS–ANALYSIS AND RESULTS

34 participants filled in the questionnaire. 2 did not complete the questionnaire and were excluded from the analysis. That left 32 participants in total. 23 were male, 9 female. 23 participants owned a car and 9 did not (no statistically significant correlation with gender, $r = 0.227$, $p = 0.211$). 18 indicated driving a maximum of 1.000 km per month, 6 drove 1.000-2.000 km, 6 drove 2.000-5.000 km, one drove over 5000 km a month and one participant indicated they didn't know their monthly mileage.

Overall, participants had a slight preference for the HUD (15, 46.88%), over the central console display (11, 34.38%), and the speedometer display (6, 18.74%). Answers to the questions were analysed using a series of repeated measures t-tests. Due to the number of comparisons run on the data a Bonferroni correction was applied which put the alpha used at $p = 0.0023$. A single value was significant. This was for the question where participants indicated they were more used to looking at their speedometer than a HUD ($t = -3.503$, $p = .001$). Since few cars are equipped with HUDs while all cars have speedometers, this information was obviously not informative or beneficial for choosing a location.

We chose to select the HUD combined with an auditory chime based on both its advantages offered as described in the literature (Section I-D), and based on the trend that slightly more participants preferred that location. The results indicated that drivers, at least in their self-reported answers, show little differences in preference, perceived safety, and perceived ease of the different locations tested. This runs contrary to earlier research where participants had a strong preference for the HUD, likely based on a novelty effect [54]. Perhaps now, nearly 15 years later, participants are more used to these systems despite them not being widely available in cars yet.

Most drivers (25) indicated they liked having the audio chime available to alert them to whenever an advice becomes available, although 16 of the 25 indicated they would like to have the option to turn the chime off. We used a 7-point scale that ran from −3 (disagree completely), to 0 (neutral), to 3 (agree completely). Results are displayed in table 3-a. On average, participants felt the chime helped them know an advice had become available, was appropriate, was not annoying, was not unnecessary, and would not startle them. Participants indicated it would not help them keep their eyes on the road, nor would it help them understand the advice. The latter was expected, as the chime was designed to alert drivers and did not vary based on the type of advice. The fact that participants indicated it would not help them keep their eyes on the road might be because the chime would prompt them to look at the interface. This again raises the importance of taking the driving context into consideration when choosing to communicate to the driver using in-car technology [8].

The questionnaire also inquired into whether haptic feedback in the steering wheel would be preferred to signal a new advice. Three types of vibrations were presented to the 32 participants (left side, right side, both sides). The vibrations were positively evaluated in only 14 cases (14.58%). In the 42 cases the vibrations were disliked (43.75%), and in 38 (39.58%) cases the vibrations were evaluated positively if there was a way to turn them off. In 2 (2.09%) cases no evaluation was recorded.

We also inquired about whether to provide context for the advice, meaning whether to precede it with the reason for the advice and conclude it with feedback about the performed behaviour. Questions were again answered on a 7-point scale from −3 (disagree completely), to 0 (neutral), to 3 (agree completely), and results are shown in table 3-b. Participants indicated providing the reason prior to the advice helped them understand the advice better. Providing the reason before the advice also made it more likely they would follow the advice, did not feel unsafe, and was not confusing. On average participants were neutral about the necessity of providing the reason and whether it would be distracting. This neutral rating on necessity is remarkable, since participants indicated that providing the reason for the advice would help understand the advice and would make it more likely an advice will be followed.

TABLE 3. Summary of results of the second questionnaire.

a. The audio chime:	Mean (SD)
tells me when an advice is available	1.625 (1.516)
is appropriate	1.063 (1.600)
is annoying	-0.969 (1.741)
helps me understand the message	-0.438 (1.519)
is unnecessary	-1.313 (1.570)
helps me keep my eyes on the road	-0.594 (1.599)
might startle me	-0.781 (1.653)

b. Presenting the reason for the advice	Mean (SD)
helps me understand the advice	1.500 (1.455)
makes it more likely I will follow the advice	1.667 (1.655)
is unsafe	-1.167 (1.485)
is unnecessary	0.200 (1.759)
is confusing	-1.100 (1.620)
is distracting	-0.167 (1.593)

c. Giving me feedback about my behaviour	Mean (SD)
motivates me to follow the next advice	-0.333 (2.055)
is unsafe	-0.867 (1.688)
is unnecessary	0.567 (1.909)
is distracting	0.033 (1.906)

Table 3-c displays results regarding providing feedback about the consequences of (not) following an advice. Providing the feedback was perceived as safe, and somewhat necessary. Participants were neutral about whether the feedback would motivate to follow more advices, or whether it would be distracting. The latter is likely because the participants lacked hands-on experience with the advices and as such were unsure about the effects of receiving the feedback.

E. INTERFACE AND PERSUASIVE MESSAGE CHARACTERISTICS–CONCLUSION

In this section we described the two questionnaires that were distributed. The goal of the questionnaires was to find driver preferences among the modalities used for the advice, its location, and how to best present the advice.

Results showed that participants preferred having an audio-visual multimodal interface where the advice was preceded by an auditory chime, and the advice displayed through a HUD. Adding haptic feedback was generally disliked, especially when the option to turn the vibrations off would be unavailable, we therefore chose to avoid using haptic feedback in our simulator study. Providing context will help participants understand when an advice is available and make it more likely that the advice will be followed. Participants were more divided on whether to provide feedback on their behaviour. We chose to include both in our simulator study to observe the effects.

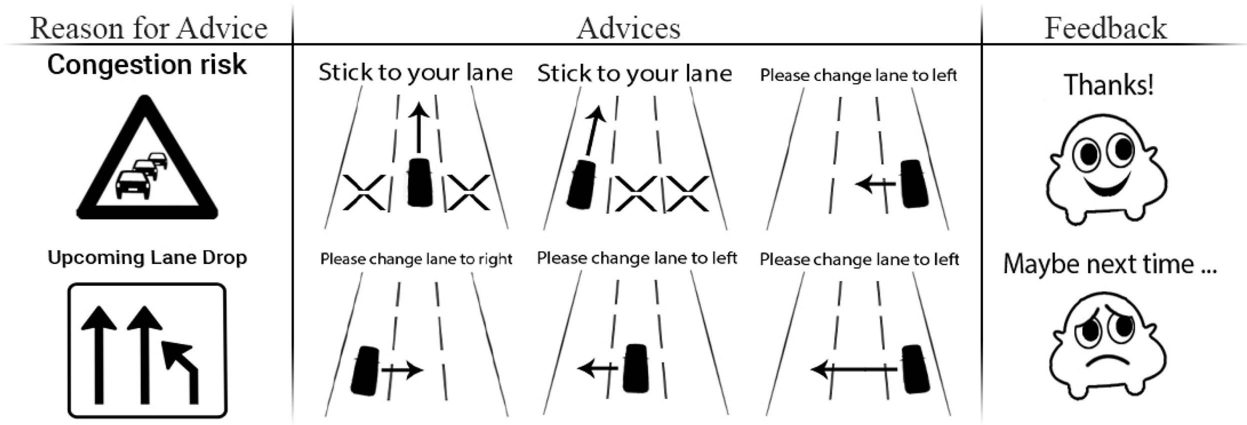

FIGURE 4. Haptic feedback was shown on the steering wheel a.), and an audio message was played through the corresponding stereo channel. Image b.) shows possible reasons for an advice. Image c.) shows the two avatar states.

FIGURE 5. Example of the three types of advices given in the simulator, in case of requiring the driver to stick to their lane. The competitive variant displayed the amount of points the driver could earn, the cooperative version displayed how many other drivers on the same road segment were following their advice.

The next section describes the development of the persuasive lane-specific advice HMI.

III. DEVELOPING PERSUASIVE ADVICE BASED ON DRIVER PREFERENCES

A. LANE-SPECIFIC ADVICE

Based on the results from the questionnaire studies, we developed persuasive advices that were preceded by the reason for the advice, and followed by feedback on the driver behaviour. Three types of advices were developed, two persuasive variants and one control. Advices for all conditions followed the same basic design of a diagram of the road with the ego vehicle displayed on the current lane as displayed in Fig. 4. The reasons for the advice were based on standard signage in use on Dutch motorways, so as to be quickly recognisable by participants. The reasons used in the experiment were congestion, and a lane-drop where the right lane would drop off. This type of lane-drop may occur when an incident has happened on the right lane, when there are road works, or where the rush-hour lane terminates.

We split the gamified group into two conditions to be able to incorporate both competition and comparison from the study by Orji *et al.* [26] as discussed in Section I-C. Among the persuasive advices were a competitive type and a cooperative type. Variations for the competitive and cooperative group are displayed in Figure 5. In the competitive group the number of points to be earned is clearly displayed below an advice, and in the cooperative group the percentage of other drivers following their advice is displayed. Participants were informed that the number of drivers following their advice included those adhering to 'stick to your lane' advices.

B. GOING ONLINE: A WEB-PORTAL INTERVENTION

To limit effects on workload while driving, we chose to keep the advices simple and add a Web-portal for both intervention groups. In this Web-portal, drivers could at their own pace review their performance parameters. These included a page with information on their latest trips, as well as a page with the progress made to the next achievement. Aside from an insight into their performance, the Web-portal gave participants an extended interaction with the avatar, whose emotion and comments changed depending on how well the participants had performed during their first driving session. The avatar's two emotional states are shown in Figure 1 and the full range of responses are shown in Table 4. The Web-portal is shown in Fig. 6.

The Web-portal had a competitive and a cooperative variant. In both versions the avatar gave feedback to the driver depending on what part of the interface the participants clicked. Both versions also showed the participant's name, score, latest trip summary and next achievement. The information on the latest trip was dependent on the performance of the participants in their first driving session. The points required to unlock the next achievement were also based on performance during the drive, but scaled so that it was always attainable by following more advices on the second day than on the first, or an equal number of advices if all were followed the first day.

The competitive version had a leader board showing the participant's relative position to others. Like the upcoming achievement, the position on the leader board was also fixed for all participants. First place was always attainable by following more advices on the second day than on the first,

TABLE 4. **Conditions and avatar comments in Web-portal.**

Advices followed	Home page	Latest trip page
0 out of 4 *(sad avatar)*	Too bad [Name], can you do better next time?	You followed 0 out of 4 advices. That's too bad, can you try following more next time?
1, 2, 3 out of 4 *(happy avatar)*	[Name] you are doing good! Can you do better next time?	You followed [1, 2, 3] out of 4 advices. That's cool! Can you try following more next time?
4 out of 4 *(happy avatar)*	[Name] you are doing great! Can you keep it up?	You followed 4 out of 4 advices. Wow! Can you do that again next time?

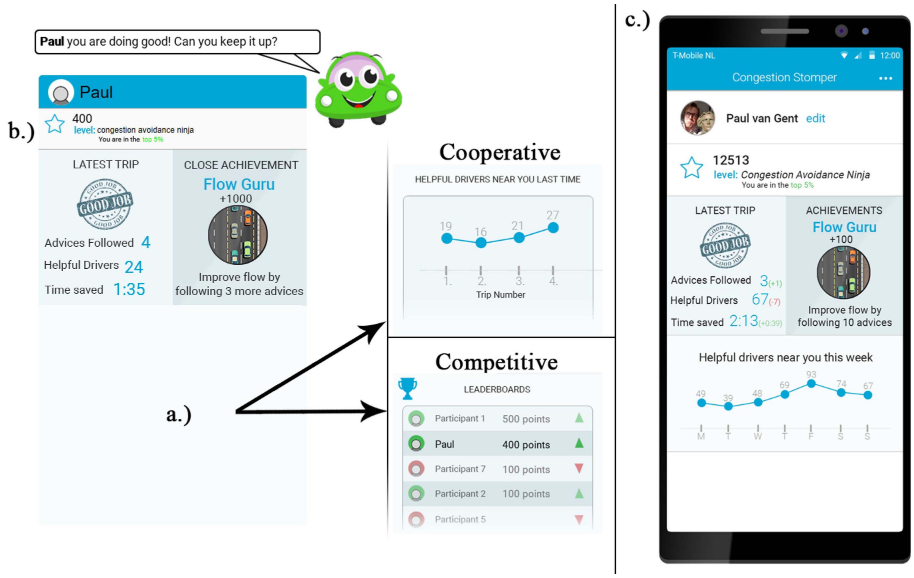

FIGURE 6. **The Web-portal that was developed. Part a.) was variable. More information on the rank of the driver (i.e., 'top 5%' as shown in b.)) was only shown in the gamified condition. Part c.) shows an example of the cooperative portal as it looked when viewed on a phone.**

or an equal number if all advices were followed the first day. The cooperative version of the Web-portal showed the number of other drivers on the road that followed their advice while the participants were driving, including 'stick to your lane' advices.

IV. SIMULATOR EXPERIMENT

This section discusses the equipment used in the experiment, the scenarios developed and the procedure that was followed while collecting the data. In the simulator study we chose to use a persuasive approach that combines the mentioned techniques from the PSD that were found to work well across different personalities [8], [23], [26]. To include the competition and comparison elements we decided to split the experiment into three groups: a competitive group where drivers could earn points and compete through a leader board, a cooperative group where drivers had real-time insight into how many other drivers followed their advices, and a control group. To incorporate the self-monitoring and suggestion without distracting the drivers we chose to implement a Web-portal where drivers could review their performance (see figure 4, Section III-B). Praise and rewards were implemented using an avatar (see figure 2, figure 1, Section I-E), which we hoped would be instrumental in forming habits, which are a main factor in making persuasive effects last over time [53]. In this context it is a form of "dialogue support" and "primary task support" from the PSD [23] and our theoretical framework [8].

A. EQUIPMENT

A medium-fidelity driving simulator was used to perform the experiment. It consisted of three 4K (resolution 4096 * 2160 pixels) displays mounted on top of a dashboard mock-up. It provided participants with roughly 180-degree vision of their virtual surroundings. Fanatec steering wheel and pedals were used along with custom key-based ignition and blinker controls were used. The simulation was run on the Unity3D game engine on a Windows 10 desktop pc.

Car kinematics were logged in Unity3D on the simulator pc. Participant responses and video recordings were logged on a Windows 10 laptop computer situated behind the participant out of their view, as not to be distracting.

B. SCENARIOS

We developed a congestion scenario and a lane-drop scenario. In the congested scenario, participants encountered a traffic jam after driving for several minutes. In the lane-drop scenario, participants encountered a lane-drop after the same amount of time had passed. We varied whether the reason for the advices was visible to the participants. In two scenarios the reason for the advice was visible ('congruent' scenarios), and in two others the reason for the advice was not visible ('incongruent' scenarios). For example, in a congruent lane-drop scenario participants encountered signage indicating an upcoming lane-drop together with a lane-specific advice, whereas in the incongruent version the signage and lane-drop were not encountered but the advice was given nonetheless. The same was true for the congested scenario; in the congruent version the overhead matrix signs indicated a reduced speed limit and a congested section was encountered, whereas in the incongruent version the traffic jam was too far ahead to be visible and no signage was active, but the advice was given. This gave a total of four scenarios. The type of advice was either non-persuasive (control group), competitive (competitive group), or cooperative (coop group) in nature.

Advices were developed as described in Section III-A. During the drive the advice was projected on a Heads-Up Display (HUD) in the centre of the car window. The choice for a HUD was made based on the questionnaire research and relevant literature, as described in Sections I-E and II-D. The HUD was made semi-translucent, so it would not occlude any vital information from participants. In the competitive variant, the number of points to be earned was displayed below the advice, in the cooperative variant this was the percentage of other drivers currently following their advice.

Each scenario started on a highway-side parking lot. Participants had to start the vehicle, navigate off the parking area and merge onto the highway. After approximately two minutes participants were given an advice on the car's HUD. This advice was preceded by an alert that specified the reason for the advice (figure 4, left). The advice (figure 4, middle) was active for approximately 1.5 minutes and was lane-sensitive, meaning that the advice (change left, change right, stick to lane) updated real-time based on the lane participants were driving. After the advice period ended, feedback (figure 4, right) was displayed based on whether participants followed the advice. Traffic was programmed to drive defensively and give way to participants whenever they turned on their blinker or started a lane change. This was done to eliminate the situations where participants could not change lane due to other traffic as much as possible, so that we could observe the effects of the advices. It is also in line with our design goals of only generating an advice when the driver has the opportunity to follow it and when it is safe to do so [8].

In the congestion scenario, participants were advised to either change to the middle lane of the three-lane highway, or stick to the middle lane if they were already driving there. In the congruent scenario the matrix signs above the highway were switched on and displayed a dynamic speed limit of 80 km/h. Congestion was visible in the distance when the advice was given, and participants approached slow moving (15-20km/h) traffic while the advice was active. In the incongruent scenario, traffic was driving with a regular speed limit of 130km/h, the dynamic speed limit signs were off, and no congestion was encountered by participants.

In the lane-drop scenario, participants were advised to move to the leftmost lane in anticipation of the righter most lane dropping off. In the congruent scenario, signs announcing the lane-drop were posted at 1 km, 300 meters, at the start of the weaving section, and near the end of the weaving section, as specified by Dutch traffic regulations. In the incongruent scenario no signage was visible and no lane-drop was encountered by participants.

C. COMPETITIVE AND COOPERATIVE INTERVENTIONS

Advices in the competitive version of the scenarios displayed the amount of points that participants could earn by following it. In the cooperative scenario the percentage of drivers currently following their advice was displayed alongside the advice. In the control group no extra information was displayed. See figure 5 for a visualisation of all three variations.

Participants were recruited to drive on two separate days, and in between both days those in the competitive and cooperative groups received a link to the Web-portal. The two versions of the Web-portal that showed the same general information but emphasized different aspects. The competitive version accentuated the amount of points earned, and participants could view their position relative to other participants through a leader board. Unbeknownst to the participants the Web-portal placed every participant as second. The point-gap between them and the first position could in all cases be closed by following more advices on the second day. The cooperative version of the Web-portal emphasized how many of the other drivers on the road followed advices. These data were fabricated and showed an upward trend of more drivers following advices recently.

For both groups the portal showed the travel time saved, advices followed, and their next achievement. The avatar communicated their performance and encouraged them to either keep up good performance when all advices were followed the first day, or encouraged participants to follow more advices the second day if they did not follow all advices during the first day. The avatar also communicated relevant details about their performance when they clicked the different parts of the site. Both Web-portal versions are displayed in figure 6.

D. PROCEDURE

A pilot study was performed to test the equipment, scenarios and experimental procedure. The hardware functioned properly, and participants had no trouble performing the tasks.

Approval for the experiment was obtained from the TU Delft ethics committee. Participants could apply for the experiment through e-mail, after which they received a copy of the informed consent and were allowed to ask any questions. During the first session participants were seated in the simulator and had a second opportunity to ask questions about the informed consent or procedure, and signed the document when all questions were answered. A familiarization scenario was first started. This scenario had no traffic and no advices so that participants could drive at their own pace and get used to the simulator. Once participants indicated they felt comfortable driving the car, the experiment started.

Prior to starting the experiment, participants received a written instruction. The document asked participants to drive as they would in everyday life and emphasized there was no desired behaviour. Rather, participants were made aware of the fact that, just as with a real-life in-car system, it is unknown what the accuracy of the given advice is. In the competitive group, participants were told they could earn points by following the advice and that the potential rewards would be displayed with the advice message. Those in the cooperative group were instructed that the system was a cooperative system that only worked when most of the people on the road followed the advices, and that the number of computer-controlled cars that 'chose' to follow their advice would be displayed real-time on the advice as well.

Participants were randomly assigned to control, competitive or cooperative groups and drove the four scenarios in a randomized order. At the end of the session participants filled in the van der Laan scale [55], a short questionnaire that measures perceived usefulness and satisfaction with advanced in-car systems.

Those in the competitive or cooperative group received an e-mail with a link to the Web-portal after the first day, where they could view their performance in a personalised version of the portal. On the second day participants drove the same scenarios as the first day, again in a randomized order. At the end of the second day the van der Laan scale was filled in again.

During the familiarization drive and between scenarios, participants were asked for signs of discomfort and/or simulator sickness, and asked to indicate it the moment they experienced any discomfort.

V. RESULTS

A. PARTICIPANT DEMOGRAPHICS

A total of 55 participants took part in the experiment. One participant dropped out due to simulator sickness. 24 (44.4%) of participants were female, 30 (55.6%) male, with an average age of 36.19 years (SD: 10.75). The participants were assigned randomly to conditions (control, competitive, cooperative) with 18 participants per condition.

All participants held a valid driver's license and drove regularly. 30 (55.6%) of participants drove at most 1,000 km per month, 14 (25.9%) between 1,000 and 2,000 km, 8 (14.8%) between 2,000 and 5,000 km, and 1 participant (1.85%) over 5000 km per month. One participant (1.85%) didn't know how many kilometres they drove every month.

28 participants (51.85%) indicated they regularly used a navigation device in while driving, 21 (38.89%) sometimes, and 5 (9.25%) rarely to never used a navigation device while driving.

B. PERSUASIVE EFFECTIVENESS OF INTERVENTIONS

First, we analysed the total advices followed by each group. Levene's test for equality of variances indicated the assumption of equality of variances was violated, so instead of a T-test we used the Mann-Whitney U Rank Test, which does not assume equality of variances. With each result we give the test statistic 'U' and significance level 'p'. Out of 144 advices, participants in the control group followed 89 (61.81%) advices, in the competitive group 117 (79.17%) advices, and in the cooperative group 111 (77.08%) of advices. The difference between control and competitive groups was statistically significant ($U = 8352$, $p < .001$), as well as between the control and cooperative group ($U = 8784$, $p = .002$). The difference between competitive and cooperative groups was not statistically significant ($U = 9936$, $p = .193$). This indicates that both interventions were more effective than the control group, but there were no clear differences between them in effectiveness.

Second, we analysed the effects of the intervention given between both driving days. We used a Wilcoxon-Pratt Signed-Rank test, suitable for dependent (non-normal within-participant) data, to test the number of followed advices on the first and second day. With each result we give the test statistic 'Z' and significance level 'p'. The control group followed 44 advices on the first day and 45 advices on the second day, a difference that was not statistically significant ($Z = 720$, $p = .841$). Participants in the competitive group followed 53 advices on the first day and 64 on the second day, which was statistically significant ($Z = 252$, $p = .012$). Those in the cooperative group followed 50 advices on the first day and 61 on the second day, which was also statistically significant ($Z = 252$, $p = .012$). This indicated that after exposure to the Web-interface, participants followed significantly more advices, and that the difference was not attributable to repeated exposure to the advices as the control group showed no significant difference. Results are visualised in Figure 7 a.).

Lastly, we analysed the differences between groups on the same days. Again, the assumption of equal variances was violated, so a Mann-Whitney U Test was used. With each result we give the test statistic 'U' and significance level 'p'. Each group was given a total of 72 advices per day, on both days. On the first day, participants in the control group followed 44, those in the competitive group 53, and those in the cooperative group 50 advices. The difference between control and competitive and control and cooperative groups was not significant ($U = 2268$, $p = .056$, $U = 2376$, $p = 0.148$, respectively), and the difference between competitive and cooperative was not statistically significant either ($U = 2484$, $p = .291$). On the second day, those in the control group followed 50, those in the competitive group 64, and those in the cooperative group 61 advices. The differences between control and competitive and between control and cooperative were statistically significant ($U = 1908$, $p < .001$, $U = 2016$, $p = .001$, respectively), but the results between cooperative and competitive were not ($U = 2484$, $p = .232$). This indicates the effectiveness of the intervention: the first day no significant differences between the groups were observable,

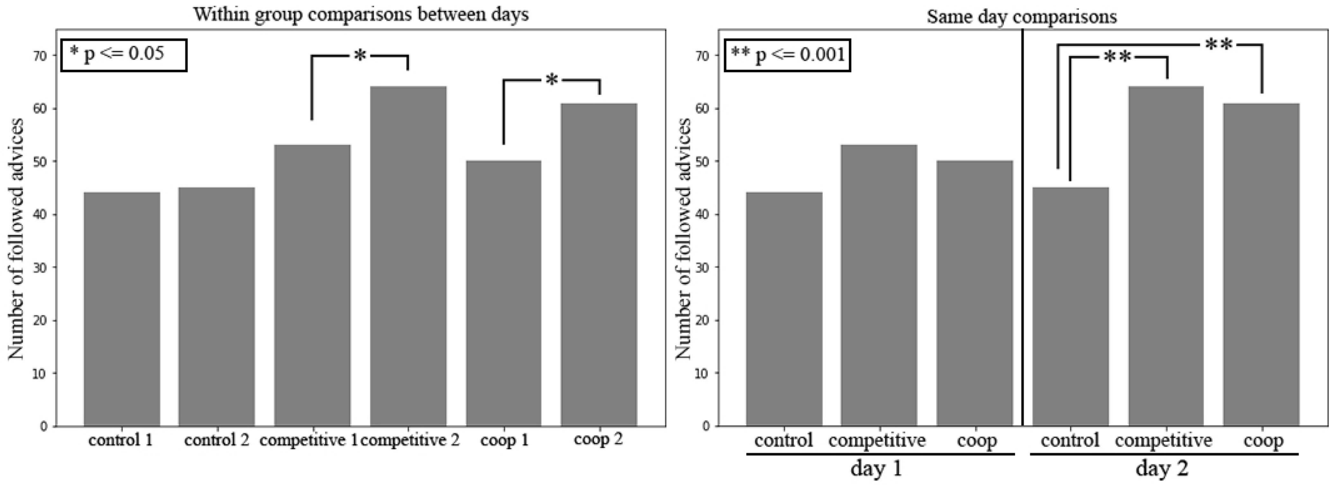

FIGURE 7. a) shows comparisons within groups between driving day 1 and 2. The right-hand plot b) shows comparisons between days. Significant differences are marked with *.

but on the second day differences emerged, with those in the competitive and cooperative groups following significantly more advices than those in the control group. Results are visualised in figure 7 b.).

Surprisingly, we found no statistically significant relation between whether or not the reason for the advices was visible (congruent vs incongruent) to the driver ($t = .377$, $p = .706$), which runs contrary to what has been observed before [50]. It is possible this discrepancy results from participants driving in a simulator rather than in the real world.

Using a t-test (test statistic 't', significance level 'p'), no statistically significant difference was found between advices followed and the lane-drop or the congestion advices on the first day ($t = 1.963$, $p = .052$), the second day ($t = .364$, $p = .717$), or both days combined ($t = 1.634$, $p = .103$). Furthermore, no statistically significant correlation was found between advices followed and gender ($r = -0.150$, $p = 0.279$), age ($r = -0.072$, $p = 0.603$), or average kilometres travelled per month ($r = 0.139$, $p = 0.312$).

C. TYPES OF ADVICES AND BEHAVIOUR

Participants were free to drive as they normally would. This meant that the types of advices given (change lane, stick to lane) were determined dynamically based on participant driving behaviour. Because this might skew results, we analysed the link between the types of advices given and the behaviour of participants as well.

In total 427 advices were given to participants during the experiment. 87 (20.37%) advices required drivers to stay in their lane, 229 (53.63%) advices required drivers to move one lane left or right, and 111 (26.00%) advices required drivers to move two lanes. No significant correlation existed between the choice to follow or not follow an advice and the number of lanes the driver had to change ($r = 0.004$, $p = 0.941$). The same held for within-group correlations for all groups: control ($r = -0.034$, $p = 0.690$), competitive ($r = -0.060$, $p = 0.478$), and cooperative ($r = 0.160$, $p = 0.056$). This ran contrary to our expectations. We expected stick-to-your-lane advices to be complied to more often, as these require less effort from the driver to follow compared to advices requiring a lane change.

D. PERCEIVED USEFULNESS AND DRIVER SATISFACTION

The van der Laan scale [55] was used to assess both the perceived usefulness of, and the participants' satisfactions with, the lane-specific advice HMI. Both the perceived usefulness and the satisfaction scales range from −2 (low usefulness, low satisfaction), 0 (neutral usefulness, neutral satisfaction), to 2 (high usefulness, high satisfaction). The assumption of normality was not violated so the data was analysed using the appropriate t-tests depending on whether dependent or independent data were being analysed. Analysis follows the same pattern as in the previous section.

First, we analysed the differences between the groups. For each test we give the test statistic 't' and the significance level 'p'. Perceived usefulness for the control group was 0.589, for the competitive group 1.072, and 1.006 for the cooperative group. The differences were statistically significant between control and competitive groups ($t = -3.531$, $p = .001$), and between control and cooperative groups ($t = -3.277$, $p = .002$), but not between competitive and cooperative groups ($t = 0.427$, $p = .672$). Satisfaction was 0.472 for the control group, 1.014 for the competitive group, and 0.931 for the cooperative group. The differences were statistically significant between control and competitive ($t = -2.949, p = .006$), and between control and cooperative ($t = -2.692, p = .011$), but not between competitive and cooperative groups ($t = 0.477$, $p = .637$). This indicates that in general, the competitive and cooperative advices were evaluated as more useful, and participants were more satisfied with them compared to the control group. We note that participants only had two short driving sessions to receive advices and become

TABLE 5. The usefulness and satisfaction scores of the lane-specific advices, both the total as well as split by day.

	Both days		
	control	competitive	cooperative
Usefulness	0.589	1.072	1.006
Satisfaction	0.472	1.014	0.931

	Day 1			Day 2		
	control	competitive	cooperative	control	competitive	cooperative
Usefulness	0.578	1.033	0.900	0.600	1.111	1.111
Satisfaction	0.486	0.931	0.847	0.458	1.097	1.014

familiar with them. It is likely that satisfaction and perceived usefulness will increase or decrease over time as participants get more experienced with the advices and their effects.

Second, we analysed the effects between driving days in the same groups. Data were analysed using a paired-samples t-test. Within the control group the perceived usefulness on day 1 was 0.578 and 0.600 on day 2, which was not statistically significant ($t = 0.163$, $p = .872$). Satisfaction was 0.486 on day 1 and 0.458 on day 2, which was not statistically significant ($t = 0.243$, $p = .811$). Within the competitive group the perceived usefulness was 1.033 on day 1 and 1.111 on day 2, which was not statistically significant ($t = -0.999$, $p = .331$). Satisfaction was 0.931 on day 1 and 1.097 on day 2, which was not statistically significant ($t = -1.531$, $p = .144$). In the cooperative group the perceived usefulness on day 1 was 0.900 and 1.111 on day 2, which was not statistically significant ($t = -1.769$, $p = .095$). Satisfaction was 0.847 on day 1 and 1.014 on day 2, a difference that was not statistically significant ($t = -1.531$, $p = 0.144$). This indicates no effects of the Web portal on either perceived usefulness of, or satisfaction with the HMI, as there is no difference after receiving the intervention, and no significant increase between both driving days. Drivers did not need the Web-portal to see the usefulness of the HMI or evaluate it as satisfying to use.

Lastly, we analysed the group differences on the same days. On the first day, perceived usefulness differed significantly between control (0.577) and competitive (1.033) groups ($t = -2.888$, $p = .007$) and between control and cooperative (0.900) groups ($t = -2.240$, $p = .03$), but not between competitive and cooperative groups ($t = 0.777$, $p = .442$). Satisfaction differed significantly between control (0.486) and competitive (0.931) groups ($t = -2.031$, $p = .050$), and between control and cooperative (0.847) groups ($t = -2.097$, $p = .044$), but not between competitive and cooperative groups ($t = 0.436$, $p = .665$). On the second day the same patterns were present, with perceived usefulness differing between control (0.600) and competitive (1.111) groups ($t = -3.239$, $p = .003$), and between control and cooperative (1.111) groups ($t = -3.053$, $p = .004$), but not between competitive and cooperative groups ($t = 0$, $p = 1.000$). Satisfaction differed between control (0.458) and competitive (1.097) groups ($t = -3.571$, $p = .001$), and between control and cooperative (1.014) groups ($t = -2.753$, $p = .009$), but not between competitive and cooperative groups ($t = 0.435$, $p = .666$). The differences between the groups remained stable over time, confirming that the Web-portal intervention did not seem to contribute significantly to overall usefulness of satisfaction scores.

VI. CONCLUSION

In this paper we outlined the development of persuasive advices for a lane-specific advice HMI, with the goal of reducing congestion.

During the driving experiment participants drove the same scenarios on two different days. Those in the competitive group could earn points by following advices, those in the cooperative group could see how many others were following an active advice, and those in the control group only received an advice. Those in the competitive and cooperative groups viewed a Web-portal in between both sessions where they could review their performance and were encouraged by an avatar. Results showed that, on a group level, the competitive and cooperative groups followed significantly more advices in total. Secondly, after exposure to the persuasive Web-portal, those in the competitive and cooperative groups followed significantly more advices on the second day than on the first, which indicates the intervention's effectiveness. Finally, the differences between groups only emerged on the second day, meaning there was no significant behavioural difference between the groups prior to the intervention, but there was a significant difference after the intervention. This indicates the effectiveness of the persuasive intervention over the control group, but shows no clear distinction between the competitive or the cooperative approach to say which is more effective.

Based on the van der Laan scale, perceived usefulness and satisfaction were higher for both persuasive groups compared to the control group, but not between them. Over time there were no significant within-group changes between both driving days, although there was a slight upward trend in perceived usefulness for all groups, as well as for satisfaction in both treatment groups but not the control group. Differences between groups were also stable over time, with the cooperative and competitive HMI's being perceived as more useful. We interpret this as meaning the Web-portal interface had no significant effect on overall perceived usefulness or satisfaction, but that both persuasive interventions were perceived as more useful and satisfying in use.

VII. DISCUSSION

Persuading drivers to follow a message that may not be in their personal benefit is a complex issue. The significant effects on driver willingness to follow advices are important in light of newly developed lane-specific (cooperative) advice systems. These systems only work to improve flow if drivers follow the advices generated, however drivers may be unwilling to do so until they see that doing so will benefit them [50], [56]. This creates a catch-22 situation where deployment of such a system may fail because for it to work drivers need to follow the advices, but drivers will not follow the advices until they see the that system works. Using persuasive advices in such a system creates an added incentive for drivers to follow the advices, which may boost the amount of advices followed, subsequently leading to drivers observing benefits from the system which further reinforces willingness to follow lane-specific advices. This way the persuasive aspects are employed mainly in the early phases when rolling out a lane-specific or cooperative system. This overcomes a major limitation of such persuasive interventions, which is that persuasive effectiveness may reduce over time [57], [58], by stimulating the formation of habits. This is a key factor in making persuasive effects last over time [53].

Based on what we discussed in this paper, when implementing persuasive in-car advice systems we recommend spreading information over multiple modalities to reduce impact on driver workload [43], to keep the eyes-off-road time to a minimum [35], and to manage driver workload by timing messages to appropriate moments [8]. Using an avatar that shared driving goals with the driver, and a Web-portal that gave insight into participant performance had a positive effect on driver willingness to comply with persuasive messages. While in this paper we describe the choices for and development of a visual advice combined with an auditory alert, an avatar and a Web-portal, the approach taken for such systems is dependent on the required behaviours and the type of advice given.

When implementing a lane-specific advice system such as the one described in this paper, the accuracy of the given advices is of paramount importance. If the information is inaccurate, trust in the system erodes over time [59] and participants might stop following advices altogether. This also includes situations where a driver may not be able to judge whether the information is trustworthy or not [50]. Any such system, therefore, must ensure its advices are correct, and that information about the reason for the advice is visible to the driver.

A. LIMITATIONS

The present work consists of two questionnaires and a simulator study. Although all possible care was taken to make the generated videos and simulator scenarios as realistic as possible, differences between simulator and real-world driving do exist. Our study shows significant effects of gamification on driver persuasion to follow advices. However, in real-world driving other factors like time-pressure, driver mood, weather conditions or the behaviour of other drivers might influence driver willingness to follow an advice, among other factors. When using a driving simulator in research, its validity is usually relative rather than absolute [47], meaning that behavioural effects found translate to the real world, but that effect magnitudes might differ. Wang *et al.* [48] performed an evaluation on using medium fidelity simulators to test in-car interfaces, and found that the effects of in-car interfaces can be effectively investigated using medium fidelity driving simulators.

The two questionnaires were based on 20 and 34 respondents, and the simulator study on 54. Self-selection bias may be present, since we put out adverts for all study steps and participants were free to apply themselves. Although the sample size is adequate for the analyses performed, as is often the case a larger sample size will make the results more generalizable. This is especially since, although the sample is diverse, it still consists mainly of Caucasian Europeans. Results may differ among ethnicities.

Lastly, since we developed the interface for a specific goal during the design phase, it is conceivable that different persuasive goals, or different environments in which the persuasive intervention is applied, will lead to different HMI requirements. This means that for different application domains, the HMI discussed in this paper needs to be validated.

B. NEXT STEPS AND RECOMMENDATIONS

Following the mentioned limitation of potential differences between simulated and real-world driving, as a next step we recommend an on-road trial to evaluate the persuasive HMI in real-world driving conditions. Ideally such a study would take place in a naturalistic driving setting over a longer period. This will give insight into how persuasive advice following might change over time.

A second recommendation relates to our theoretical model on driver persuasion [8]. To improve safety and effectiveness of the advices we suggested to time them to a moment where the driver' workload is low. This can be achieved by integrating the persuasive HMI with for example a workload estimator [60] to make the interface adaptive [61].

Third, the motivations for following an advice as offered are different between the gamified condition, where participants could earn points, and the cooperative condition, where participants mainly had a social motivation to follow advices. We know from research that different personalities are sensitive to different types of persuasion [62]. Investigating this in the context of persuasive in-car advice is an interesting avenue for future research.

Lastly, in the present study only two advice contexts were tested: congestion ahead, lane-drop ahead. More reasons for giving an advice exist, such as road works, an accident, or adverse weather conditions. Although we found no statistically significant differences in numbers of advices followed between the congestion and lane-drop scenarios, it may still be that drivers show different compliance rates to different advice contexts. This should be examined in a future study.

Regarding recommendations for applying persuasive systems to in-car settings in practice, based on what we discussed in the paper and on the results, we recommend that:

- An app or Web-portal is combined with the in-car HMI, to reduce information clutter on the in-car HMI, and for the drivers to review their progress at their own pace.
- An avatar is used to encourage drivers. The avatar should share the driver's goals.
- Auditory or haptic feedback have the option to be turned off.
- The visual HMI is only on when it needs to be.
- If an HMI is used, it is best to reduce salience (e.g., increase transparency or reduce brightness) or not use the HMI at all during conditions of poor visibility, such as fog, heavy rain, or darkness. This is to prevent dangerous situations related to the Mandelbaum effect.

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PAUL VAN GENT received the M.Sc. degree in cognitive psychology from Leiden University, The Netherlands, in 2014. He is currently pursuing the Ph.D. degree with the Delft University of Technology in the "Taking the Fast Lane NWO-TTW Project." During his Ph.D. studies, he developed and taught a two day hands-on deep learning workshop for academic staff. From 2014 to 2016, he worked with the Dutch Road Safety Research Institute, developing sensing hardware and software for instrumented studies, along with data analysis software. His research focuses on driver persuasion, driver state prediction, and the collection and analysis of physiological metrics.

HANEEN FARAH received the Ph.D. degree in transportation engineering from the Technion–Israel Institute of Technology. She was a Postdoctoral Researcher with KTH–Royal Institute of Technology, Stockholm, Sweden. She is an Assistant Professor with the Department of Transport and Planning and the Co-Director of the Traffic and Transportation Safety Lab, Delft University of Technology. Her research interests include studying the implications of road infrastructure design on road user behavior and traffic safety. In her research, she combines her expertise in transportation engineering, with her curiosity in the fields of human factors and econometrics to study these connections. She is currently examining the implications of the advances in vehicle technology and automation on the road infrastructure design and road user behavior in the framework of several national and international projects, such as: Spatial and Transport Impacts of Automated Driving (STAD), Mediating between Driver and Intelligent Automated Transport systems on Our Roads (MEDIATOR), and SAMEN (Safe and Efficient Operation of Automated and Human Driven Vehicles in Mixed Traffic).

NICOLE VAN NES received the graduation degree in industrial design engineering from the Delft University of Technology and the Ph.D. degree in social sciences from Erasmus University Rotterdam. She is a Research Manager with the Department of Human Factors in Vehicle Automation. She is leading the research on safety in the transition to the autonomous vehicle. She is a Coordinator of the European MEDIATOR Project, which focuses on optimal collaboration between a human driver and vehicle automation. She also has ample experience in naturalistic driving research. She was a Coordinator of the large-scale European naturalistic driving study UDRIVE and is actively involved in the ongoing research on the UDRIVE data. She is a Board Member of Humanist, the European network for experts in human factors in transport. She was a Guest Researcher with the Australian Road Research Board, Sydney, Australia, for three months and for one year with Monash University Accident Research Centre, Melbourne, Australia.

BART VAN AREM (Senior Member, IEEE) received the M.Sc. and Ph.D. degrees in applied mathematics from the University of Twente, Enschede, The Netherlands, in 1986 and 1990, respectively. From 1992 to 2009, he was a Researcher and a Program Manager with TNO, working on intelligent transport systems. Since 2009, he has been a Full Professor of transport modeling with the Department of Transport and Planning, Delft University of Technology, Delft, The Netherlands, focusing on the impact of intelligent transport systems on mobility. In 2017, he received the IEEE ITS Society Institutional Lead Award for the TU Delft Automated Driving Research Program. Since 2019, he serves as the Editor in Chief of the IEEE OPEN JOURNAL OF INTELLIGENT TRANSPORTATION SYSTEMS.