Incorporating Situation Awareness Cues in Virtual Reality for Users in Dynamic in-Vehicle Environments

Nadia Fereydooni, *Student Member, IEEE*, Einat Tenenboim, Bruce N. Walker, and Srinivas Peeta

Abstract—The increasing ubiquity and mobility of virtual reality (VR) devices has introduced novel use cases, one of which is using VR in vehicles, both human-driven and fully automated. However, the effects of the adoption of VR-in-the-car on user task performance, safety, trust, and perceived risk are still largely unknown or not fully understood. Blocking out the physical world and substituting it with a virtual environment has many potential benefits including fewer distractions and greater productivity. However, one shortcoming of this seclusion is losing situation awareness which becomes critical in dynamic, in-vehicle environments, even when the user is not in the driver's seat. Hence, this study aims to understand the effects of providing VR users with situation awareness cues about the real world, when riding in a human-driven or a fully automated car. The results of this driving simulator experiment provide valuable insights into passengers' experience and their information needs while immersed in VR environments. Identifying passengers' unique challenges and needs, as well as developing solutions for them, is expected to improve users' travel experience towards a wider adoption of VR devices.

Index Terms—Virtual Reality, Situation Awareness, Perceived Risk, Fully Automated Vehicles

1 Introduction

Total commute time has been steadily rising, such that the average one-way commute in the US increased about 10% from 2006 to 2019 [7]. The US department of transportation reported that the number of trips traveled by each person on private or public transport in 2019 exceeded 3,000 trips [43]. The report states that for local travel, trips to and from work are the longest and trips for social and recreational purposes closely follow. Those journeys, however, are often repetitive, and travelers often consider their travel time as wasted [29]. Longer commutes are also associated with decreased job satisfaction and increased risk of physical and mental health issues [12, 15]. Passengers' use of Virtual Reality (VR) in cars has been proposed to improve this experience, since the advances in VR hardware have expanded the contexts that they can be used in. Moreover, the growing prevalence of ride share services in the US and globally [10, 67], and commuters' urge for productivity during travel [81] are expected to increase passengers' use of VR in cars [4, 51]. The benefits of this adoption are envisaged in terms of increased productivity as a result of working during the commute [21] and potential entertainment [41, 48]. Paredes et al. [66] proposed the use of VR in a vehicle to deliver a calming and mindful experience to the passengers. Moreover, VR can influence users' time perception [77]. There have also been suggestions of professional uses of VR in the vehicle, such as firefighters or tactical response units donning VR goggles while en route to a scene, in order to become familiar with the (real) building they are about to enter [95]. There is increasing recognition of the importance of the potential of using VR in the transportation domain across multiple international companies: Holoride [42] is working to create dynamic VR entertainment experiences for car passengers; and Renault partnered with the gaming company Ubisoft to create a VR experience that users can enjoy while they are riding in Renault's self-driving car [1].

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Manuscript received 11 March 2022; revised 11 June 2022; accepted 2 July 2022. Date of publication 01 September 2022; date of current version 03 October 2022. Digital Object Identifier no. 10.1109/TVCG.2022.3203086

Although the benefits of passengers' use of VR in cars, whether fully automated or human-driven, are apparent, there are potential harms or perceived harms that may prevent users from using VR in mobile contexts. The dynamic nature of the car that the users' are riding in, other cars, the roads, and users' lack of awareness of them due to wearing the headset impose psychological distress for the users [51]. It is proposed that providing information about the real world in the virtual environment may reduce users' distress and allow them to enjoy the potential benefits of using VR in a car [22]. In this paper, we report on an experiment aiming to study the effects of providing this information on users' perceived risk, workload, and information needs. The goal of the study is to understand how providing such information affects users' virtual experience, in two different modes of transportation. Namely, we focused on human-driven vehicles (HDV) and Fully Automated Vehicles (FAV) since both have been proposed as potential environments for using VR on-the-go [1, 41, 42, 66]. We examined the following research questions:

RQ1. How does the provision of situation awareness (SA) cues about the real-world in the virtual environment affect passengers' experience, in terms of their information needs, perceived workload, and perceived risk?

RQ2. How does the automation level of the vehicle influence passengers' experience in terms of their information needs, perceived workload, and perceived risk?

2 Background

2.1 Mobile VR

The advances in VR hardware have resulted in a growing number of contexts in which such devices are used. The growing adoption of VR devices in home and office [32, 70] will create user expectation to continue using their device in transit [58]. Users are not required to be stationary to get immersed in a virtual environment and enjoy the benefits of VR, since a growing number of devices are portable and standalone (e.g., Oculus Quest), [40] and can accommodate users' movement. Users can wear a headset while walking in the real world [14] or riding in a vehicle [52]. Some of the initial research on the use of VR in cars have focused on exploiting vehicle motion for generating a greater sense of presence and immersion in VR [41,48,66]. For instance, Kodama et al. [48] developed a VR entertainment experience that used a car as a motion platform, where the VR content was congruent with the car's motion in the z axis (forward and backward). Other studies have also developed virtual experiences for passengers that are closely linked to the perceived physical motions of the car [34, 41]. Another proposed case for using VR in cars is when the driver or the passenger wears a

Head-Mounted Device (HMD) and their ride experience is augmented by VR content [53, 80], for example traffic or infrastructure different from the real world [42, 53, 80, 90]. Cars are not the only proposed moving environments for VR adoption; busses, trains, and planes are among other transportation means where users can get immersed in a virtual environment [4, 27].

VR may also assist passengers of FAVs - where the driver role no longer exists - in engaging in Non-Driving Related Tasks (NDRT) such as work [62] and entertainment [35, 42]. The increased automation of the driving task in FAVs allows users to reclaim their travel time and overlay it with activities of their choice. The NDRTs performed in FAVs can include reading, watching a video, engaging in work, and so on [38, 68]. Kun et. al [49] grouped these tasks into the categories of communication, play, and work tasks for non-active drivers. Currently, a majority of NDRTs in FAVs are performed on 2D screens [76, 92], and little attention has been paid to NDRTs beyond the use of phones and laptops. Those technologies have many shortcomings in comparison to VR in providing users with rich and immersive experiences, and do not allow for some functionalities that the users might need [56]. In many of the named application domains, the use of VR has been proposed to enhance engagement and performance [2, 24, 61, 88]. Introducing VR as an NDRT in an FAV creates a wider variety of tasks that are possible in this emerging environment. VR can also mitigate some of the negative perceptions of FAVs, especially related to loss of control and potential boredom [71].

Whether used in HDVs or FAVs, VR introduces many benefits to passengers, as discussed above. At the same time, the occluded view introduced by the device and the lack of situation awareness about the vehicle and other cars on the road may increase users' perceived risk of using VR in a car. Perceived risk is one of the constructs affecting user trust in technology, which in turn, influences successful integration and use of technology [84]. Although there have been many studies developing various virtual experiences for in-vehicle use, whether the car is human-driven or fully automated, the study of the implications of this adoption on users' perceived risk is lacking. This paper is a step towards addressing this gap.

2.2 Perceived Risk

Regardless of the actual presence of risk, the presence of vulnerability and perceived risk dictates users' adoption of technology [85]. A known component of perceived risk is risk domain. Stuck et al. [84] defined the identified risk domains in the literature. These definitions are provided in Table 1. The domain in which risk is involved influences the perceptions of risk or risk-taking behavior [25, 93]. Even in the context of everyday technologies such as smart televisions, the levels of perceived risk are impacted by the domain [85]. Understanding the importance of each domain is also critical for designers and developers, as they can provide solutions targeted to each domain; for example, if a designer or a developer understands that the perceived risk is focused on social risk rather than financial risk, they know to look at ways of mitigating social risk instead of focusing on making the technology cheaper to purchase or less expensive to maintain.

In terms of the use of VR in dynamic environments, each risk domain leads to different research questions and design considerations. For instance, perceived social risk brings up questions about the risk involved with the presence of others in the physical room when using a VR headset, while the privacy domain opens up conversation about the data collected about users and their physical surroundings. Hence, to alleviate users' perceived risk of using VR in cars, each risk domain needs to be considered separately. Some of the risk domains have been studied more than others in the context of the use of VR in cars. For example, one instance of perceived physical risk is the fear of experiencing motion sickness [58]. Many people experience motion sickness when watching videos, reading, or working in vehicles, meaning that they cannot use their time productively. The same effect may exist for using VR in cars since these devices occlude visual perception of reality and the car's motions [57]. Several studies have investigated ways to remove this sensation through minimizing sensory conflict [57, 66].

Perceived social risk has been another domain of interest for VR in car; the loss of awareness of other passengers means that the VR users may accidentally disrupt others or physically invade their space [4, 58]. For instance, Ng et al. [62] found that users considered horizontal display layout in the virtual environment uncomfortable even though this layout was favorable with respect to ergonomics and neck range of motion; the users reported that the possibility of colliding with others or appearing to look at others while performing the VR task made this layout less preferable. Another perceived social risk that arises when using VR in a car is that other passengers may not know if they are visible to the VR wearer and may be unsure if and how they can interact with them [33].

Table 1. Perceived risk domains and their definitions adapted from [84]

Risk Domain	Definition
Ethical Risk	The technology could be immoral
Physical Harm Risk	The technology could hurt someone
Financial Risk	The technology could someone to lose money or cost lot
Security Risk	The technology could be vulnerable to misuse or is threat to safety
Social Risk	The technology could influence how other people think of the person using it
Psychological Risk	The technology could cause emotional or psychological harm or not align with how the user thinks of themselves
Time Loss Risk	The technology could be late, delayed, inefficient or require extra effort
Privacy Risk	The technology would expose the user or their environment
Performance Risk	The technology could function improperly or not completing the tasks could cause other negative outcomes

Perceived psychological risk is another important perceived risk domain in the context of the use of VR in cars. This domain includes users' perception of emotional and psychological harm [84]. VR users cannot glance at the road or keep the road in their peripheral vision, which may cause distress and perceived psychological risk [20]. Other studies have also expressed users' need to be aware of the real world while using VR [4, 60]. This need for awareness is more accentuated in dynamic environments [51]. Hence, it needs to be investigated more thoroughly for a better understanding of the use of VR in dynamic, mobile contexts.

2.3 Situation Awareness

Blocking out the physical world and substituting it with a virtual environment has many potential benefits including fewer distractions and greater productivity [5, 61]. However, one shortcoming of this seclusion is losing situation awareness (SA), which is a person's perception and knowledge of a dynamic environment, and their ability to use this information for predictions and subsequent actions [69]. A survey of VR users found that they often desire to receive information about the physical space ("someone is about to tap your shoulder") and information about auditory cues ("someone in your room is calling your name") while being immersed in the virtual environment [31].

Some studies have developed mechanisms that notify users of surrounding physical objects so they do not collide with them. These mechanisms are solutions to both perceived physical risk and perceived psychological risk; users may have a fear of colliding into real world objects while moving in the virtual environment, whether the actual collision risk exists or not. Oculus Guardian [63] and HTC VIVE's play area [11] are examples of initial attempts to ensure users stay within a safe area while performing VR tasks. Another mechanism is Reality Check [37] that merges virtual and physical environments, enabling users to be aware of their surroundings while immersed in the virtual environment. In another proposed solution [46], the device notifies the user of upcoming obstacles while they are walking. Other approaches include redirecting users' walking path to prevent them from colliding

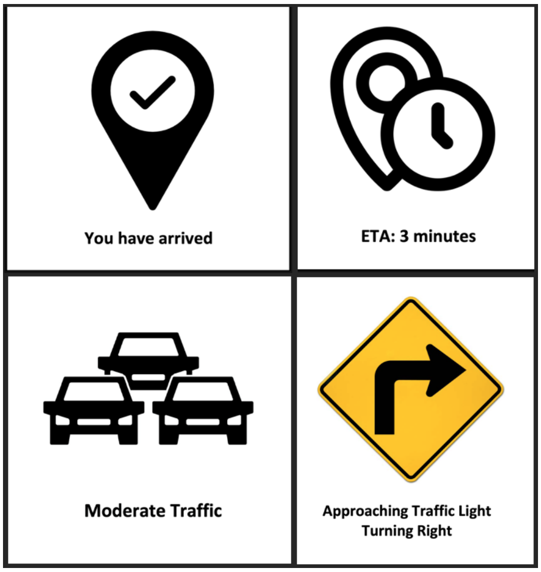


Fig. 1. Examples of the SA cues displayed during the VR experience in the *Cue* condition

Fig. 2. Example of an SA cues displayed during the Las Vegas VR experience in the *Cue* condition. The cue followed users' line of gaze.

with static objects [45, 83] or moving people [86] in the real world.

Other solutions for providing users with information about the real world are at the intersection of perceived psychological and social risk; these solutions use cues to notify VR users about non-immersed bystanders in socially related, non-critical interaction contexts [60, 64, 65, 79]. Various modalities such as audio, haptics, and visual displays, have been investigated for communicating real world information in the virtual environment [30, 31, 55, 64]. Given the growing number of solutions bridging the real world and the virtual environment, it is important to consider the effect of these cues on users' perceived risk and other aspects of the virtual and real-world experiences such as workload. The real-world context of the use of VR device (e.g., dynamic or in-vehicle) should also be considered [20, 23].

3 METHODOLOGY

3.1 Participants

The experiment included 30 participants. Data from two participants were omitted due to technical difficulties during the experiment (1 male and 1 female). The age of remaining participants (13 female, 15 male) ranged from 18 to 46 years (M = 25.5, SD = 7.2). We recruited participants from a large US university's research subject pool and via word of mouth. Participation criteria included sufficient mobility to use a VR device, and normal or corrected-to-normal vision and hearing. Participants had held a driver's license for an average of 7.4 years (SD= 7.7). Ninety percent of participants had some level of familiarity with automated driving features such as Lane Keep Assist and Cruise Control; 20% owned a vehicle with automated driving features, 23.3% had driven one, 30% had ridden in one, and 16.7% were familiar with such features. Fifty percent of participants had used a VR device before, and 23% of them stated that they use a VR device at least a few times per year.

3.2 Experiment Design

The experiment included a 2 x 2 mixed design, studying the effect of two independent variables (SA Cues, and Vehicle Automation Level) on users' perceived risk, situation awareness, and perceived workload. SA Cues was a between-subjects variable, with two levels (*Cue* and *No Cue*). Vehicle Automation Level was a within-subjects variable with two levels (*Fully Automated Vehicle (FAV)* and *Human-Driven Vehicle (HDV)*). Each participant was a passenger in both levels of Vehicle Automation and a researcher sat in the driver seat in the *HDV* condition. The purpose of the study was to explore how the provision of (or lack of) SA cues in the virtual environment affects a participant's in-vehicle experience, depending on the Vehicle Automation Level of the car. The order of the four conditions was counterbalanced using a Latin Square Design.

The VR experience consisted of aerial tours of two different cities, Las Vegas and Rio de Janeiro, each presented during a participant's two drives. The aerial tours were taken from AirPano VR YouTube channel [91] and were adapted for VR. The order of the VR tours was counterbalanced. During the tours, participants were flying through each city and listening to a narrative highlighting different landmarks. Each tour was about 5 minutes long to minimize the buildup of cybersickness symptoms and fatigue [16, 47]. The VR experience was designed to be a passive task, without the need for the participants to actively interact with the virtual content. We decided to use a passive task instead of an active task to minimize the effects of confounds such as limited space of the car or participants' potential concern of breaking social norms by rapidly moving their hands in the car.

In the *Cue* condition, participants received cues about the real world while they were immersed in the virtual world. Figure 1 depicts examples of the cues displayed in the virtual environment. These cues consisted of information about various events on the road and the car's actions, such as the car turning left or right, traffic status, estimated time of arrival, etc. The cues were crafted following icon design guidelines [13, 54]; each consisted of an image of the relevant standard traffic sign, accompanied by a short text underneath explaining the event or the car's behavior. Each VR tour consisted of five cues, and the time of the appearance of each cue was synchronized with its respective event on the road. Each cue followed the user's line of gaze to ensure they would see the cues, and appeared for 5 seconds to allow enough time for the user to perceive the icon and read the text [9]. Figure 2 displays an example of an SA cue in the virtual environment.

3.3 Apparatus

An RDS-2000 Full Cab Driving Simulator was used in this study (see Figure 3). This simulator consists of a vehicle cabin (2013 Ford Fusion) with automatic transmission, a surround-sound system for engine and environmental noise, and a six degree of freedom motion platform that can move and twist in three dimensions and vibrate to generate the road rumble feel. The vehicle is surrounded by five front-view projectors providing nearly 360 degrees high-resolution field view to drivers. This simulator is equipped with SimDriver, a fully automated vehicle control system. Once SimDriver is activated, the simulated vehicle is at SAE Level 5 automation (aka fully automated) [44], in which the driver role no longer exists. The driving scenarios in both drives for each participant were identical, and SimDriver was activated in both drives (i.e., the *HDV* and *FAV* conditions) to ensure a comparable baseline, even though an experimenter pretended to drive in the *HDV* condition.

The VR task was presented on an Oculus Quest 2, a standalone VR headset (without the need for a PC to run the application [63]). We developed the task in Unity 2019.1.2.

Fig. 3. Driving simulator setup

3.4 Measures

3.4.1 Perceived Risk

The perceived risk survey was adopted from Stuck [84]. We used the short version to measure two aspects of perceived risk:

- **Affect** is the person's emotional component of perceived risk. In other words, this aspect focuses on users' intuitive assessment of risk, demarcating a positive or negative quality to the situation or technology [82]. Affective perceived risk is measured with ten 7-point Likert items, five of which were worded positively and five were worded negatively.
- **Probability x Severity** (dubbed 'PxS') is the person's perceived **severity** with weighted **probability**. In other words, this aspect focuses on users' assessment of the probability of experiencing consequences of various severities [94]. This portion of the questionnaire included five different risk-related words, representing a range of risks ('awful', 'unpleasant', 'disastrous', 'catastrophic', 'severe'). Each word had a 5-point Likert range of severity. Participants were given 10 points for each word, and were asked to weight each of the Likert items by their probability (see Figure 4).

3.4.2 Situation Awareness

The Situation Awareness Rating Technique (SART) [87] is a self-rating measure that was administered after each of the two drives to assess participants' situation awareness. We chose this measure as opposed to dynamic questionnaires administered during the task [17, 19] to prevent the measure from breaking participants' VR presence.

3.4.3 Perceived Workload

We used the NASA-TLX questionnaire [36] to measure participants' perceived workload. This questionnaire incorporates six sub-scales to derive an overall workload score. These sub-scales include mental demand, physical demand, temporal demand, performance, effort, and frustration.

3.4.4 Post Experiment Interview

We conducted a semi-structured debriefing interview at the end of each experiment session to get a more nuanced view of the participants' experience during the two drives. Participants were asked to compare the two drives in terms of their feeling of safety and enjoyment. They were also asked to discuss the information about the real world that they would like to be aware of. Finally, the participants in the *Cue* condition were asked about the extent to which the cues affected their awareness of the real world.

3.5 Procedure

After participants signed the informed consent form, they completed a survey that included demographics questions (age, gender, culture of origin), questions about their propensity to trust [26], and their Big Five Factors of personality [72]. They were also asked if they owned, have driven, or have ridden in a car with automated vehicle features (e.g., automated lane keeping); how long they had their driver's license; if they have used a VR device before; and how often they use a VR device. After completing the demographics survey, each participant was given a tutorial on how to adjust and use the VR device. They were then screened for simulator sickness; this screening was adapted from Gable et al. [28] for VR, and consisted of a baseline survey, a brief, 2-minute screening drive in the simulator while wearing the VR headset, and a post-drive follow-up survey. The VR experience during the screening protocol consisted of a flight over the Siberian desert [91]. The survey software automatically scored the participants' pre- and post-drive responses, leading to a recommendation for continuing or exiting the study. After passing the screening, the participant was asked to imagine a scenario in which they are taking a taxi or an Uber for a short ride to get to their destination, and decide to use a VR device for entertainment during the ride. This scenario was put in place to portray a consistent frame of mind among the participants. Participants in the *Cue* group were also notified that they would receive information about the real world while immersed in VR. The participant sat in the backseat of the car and the headset was handed to them. Before the *FAV* condition, the researcher explained the capabilities of the fully automated vehicle to the participant, based on [44]. A researcher sat in the driver's seat during the *HDV* condition to make the participant think that the car was being driven by a human driver. However, the Simdriver was activated in both of the drives to ensure a comparable baseline. Twenty seconds into each drive the participant was notified that they could start their VR experience. After each drive, the participant left the driving simulator to answer questions about their situation awareness, perceived risk, and workload. Participants were also asked to list three facts they learned throughout the VR tour to check for attentiveness. At the end of the second drive, each participant was interviewed about their experience during the experiment.

4 Results

4.1 Data analysis

The responses to the attention check questions showed that participants were attentive during the passive task and paid attention to the VR tours. We ran a series of split plot ANOVAs to assess the statistical significance of SA Cues and Vehicle Automation Level, and their potential interaction on participants' perceived risk, situation awareness, and perceived workload. All the analysis was conducted in SPSS.

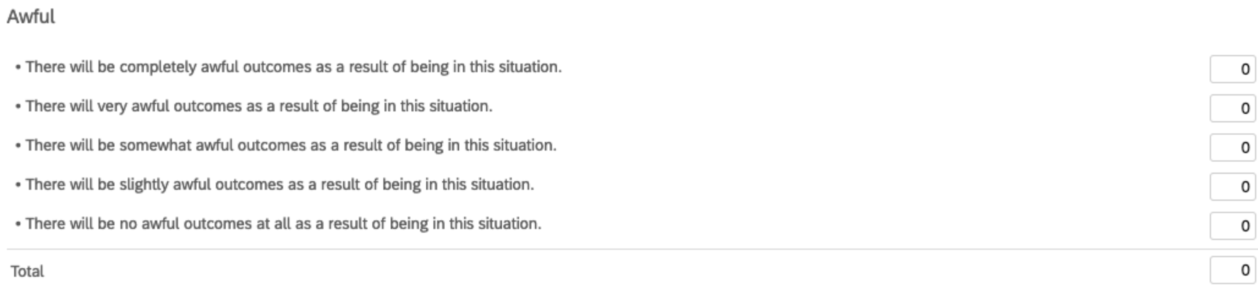
4.2 Perceived risk

The perceived risk scores for each of the affect and PxS items were determined following the guidelines described in [84]; We used a weighted Likert scale to calculate the scores for the PxS items. The probabilities assigned to each level of severity were used as a weighting between 0-10. The probability weighting was multiplied by the level of the Likert scale (i.e., 1-Not at all, 2-Slightly, 3-Somewhat, 4-Very, 5-Completely) and then divided by 10 since that is the total of probabilities assigned. This was done for each risk-related word and then these scores were totalled for the overall PxS score for that individual. The affect score was calculated by averaging its ten items after reverse coding the negative items.

Each calculated PxS score is in the range of 1-5, with 1 signifying no risk, 3 moderate risk, and 5 extreme risk. Each Affect score varies between 1-7, with higher scores demonstrating lower perceived risk and 4 indicating moderate risk.

4.2.1 Affect Items

Figure 5 shows the pattern of results for affect items. Results from the split plot ANOVA indicated a statistically significant main effect of Vehicle Automation Level on affect, $F(1, 26) = 5.582$, $p = 0.025$, partial eta-squared = 0.166. The higher average affect scores were found in the *HDV* condition ($M = 5.503$, $SD = 1.349$) while the *FAV* condition ($M = 5.036$, $SD = 1.745$) led to lower affect scores. Interestingly, the SA cues did not significantly influence participant affect scores, $F(1,26) = 0.411$, $p = 0.527$. Furthermore, we did not find an interaction effect of Vehicle Automation Level and SA Cues on participant affect scores, $F(3,26) = 0.028$, $p = 0.867$. These findings suggests that the FAV lead to higher affective perceived risk compared to the human-driven car, regardless of receiving SA cues about the real world.


Awful

• There will be completely awful outcomes as a result of being in this situation.	0
• There will very awful outcomes as a result of being in this situation.	0
• There will be somewhat awful outcomes as a result of being in this situation.	0
• There will be slightly awful outcomes as a result of being in this situation.	0
• There will be no awful outcomes at all as a result of being in this situation.	0
Total	0

Fig. 4. One of the Probability x Severity items of the perceived risk questionnaire. Participants had to distribute a total of 10 points to the items of the 5-point Likert range of severity. They had to repeat this task for each of 5 risk-related words (awful, catastrophic, disastrous, severe, and unpleasant).

4.2.2 PxS Items

Vehicle Automation Level did not have a significant effect on PxS scores, $F(1,26) = 1.090$, $p = 0.305$. Similarly, the SA Cues did not significantly influence participant PxS scores, $F(1,26) = 1.575$, $p = 0.220$. We did not find an interaction effect of Vehicle Automation Level and SA Cues on participant PxS scores, $F(3,26) = 0.002$, $p = 0.962$.

4.3 Situation Awareness

The SART scores were calculated following the guidelines described in [87]. Vehicle Automation Level did not have a significant effect on SART scores, $F(1,26) = 0.029$, $p = 0.865$. Similarly, the SA Cues did not significantly influence participant SART scores, $F(1,26) = 0.410$, $p = 0.527$. We did not find an interaction effect of Vehicle Automation Level and SA Cues on participants' SART scores, $F(3,26) = 1.649$, $p = 0.210$.

4.4 Perceived Workload

The overall perceived workload scores were calculated by averaging the scores of the six subcategories in the NASA-TLX questionnaire. Figure 6 shows the pattern of results for perceived workload. The split plot ANOVA indicated a statistically significant effect of SA Cues on perceived workload, $F(1, 26) = 5.903$, $p = 0.022$, partial eta-squared = 0.174, such that the *Cue* condition showed a significantly lower perceived workload. Vehicle Automation Level did not have a significant effect on perceived workload scores, $F(1,26) = 2.449$, $p = 0.129$. We did not find an interaction effect of Vehicle Automation Level and SA Cues on participant workload scores, $F(3,26) = 0.326$, $p = 0.573$.

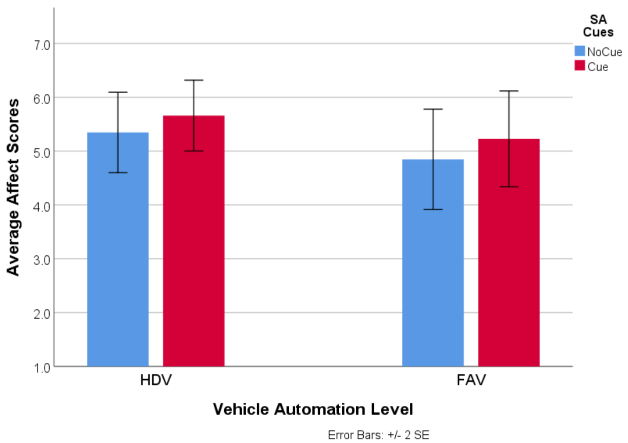


Fig. 5. Average affect scores compared by SA Cues and Vehicle Automation Level

4.5 Post-experiment Interview

In addition to the quantitative data, qualitative data from the interview provided insight into the participants' experience of using a VR device in a car. The interview questions asked participants' to compare the two drives in terms of their feeling of safety and enjoyment, their road awareness, and how the provision of the SA cues influenced their experience. We conducted several rounds of open coding. Generated codes were shared and discussed by all authors after each iteration of coding. The first round of coding closely followed the text. The next round of coding was more high-level and resulted in codes such as "monitoring the driver/system", "driving stability", and "road awareness". Subsequent rounds of coding combined several codes to surface two larger themes of "trust in automation" and "informational needs" which are discussed in this section.

4.5.1 Trust in Automation

When asked to compare the two drives they experienced, some participants expressed that they felt it was safer to use VR in a human-driven car than in a fully automated car, due to their lack of experience or trust in the latter. For instance, P2 *"trusted a person more than a computer, especially when not watching it."* A few participants stated that they felt more bumps on the road while they were experiencing the *FAV* condition. However, the drives that each participant experienced for the *FAV* and *HDV* conditions were identical to ensure a comparable baseline. For instance, P14 mentioned that, *"I felt safer with the human driver. The fully automated car felt more bumpy. I trust it [the FAV] less."* Similarly, a few other participants *"felt more aware of the road in the fully automated car"* (P4) and *"felt the need to be more attentive in the FAV"* (P2), and expressed their lack of trust towards fully automated vehicles (P3,9,13). At the same time, many of the participants stated

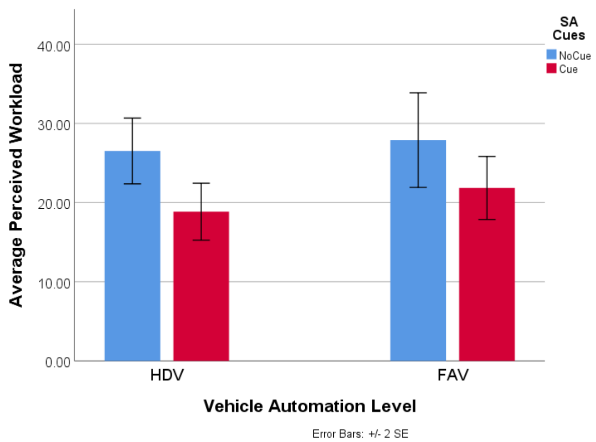


Fig. 6. Average perceived workload scores compared by SA Cues and Vehicle Automation Level

that they are aware of the higher safety level of fully automated cars, but this awareness has not translated into a higher trust in the technology yet. In fact, P1 stated that, *"Logically, I know that FAV is safe. However, FAV made me more stressed."* Similarly, P21 expressed that, *"I know that the fully automated vehicle is safer but I'm not used to it, so I feel safer with the human driver."*

4.5.2 Informational Needs

A majority of participants expressed the need to receive some information about the real world while immersed in the virtual, including information about dangers on the road (P7,15,21), time to destination (P8,10,22), directions (P5,9,27), status of their belongings (P24,26), and traffic (P5). Moreover, a majority of participants stated that the provision of this information would increase their willingness to use VR in a car. For instance, P16 (in the *No Cue* condition) stated that they would *"need some information to make me feel safe to use VR in the car."* P1 (in the *Cue* condition) explained that this need for cues depends on the "quality of driving", and that they would want to *"toggle between the VR environment and the real world view."* Similarly, P5 (in the *Cue* condition) expressed that they *"would not feel comfortable otherwise"* to use a VR device in a car.

Participants who received the cues during their VR experience differed in terms of how helpful they found the cues. Some found them to be an essential part of their experience. For example, P13 said, *"They helped me prepare for any physical motion that was upcoming."* Similarly, P23 stated, *"I checked them to to keep aware of the road... and if I was worried worried, they helped me to know what the car was doing."* However, some participants asserted that they ignored the cues and paid more attention to the VR content (P3,5,7). Interestingly, some participants expressed concern about receiving SA cues due to being distracted by them (P21,29).

5 Discussion

Blocking out the physical world and substituting it with a virtual environment has many potential benefits including fewer distractions and greater productivity [5, 22, 61]. To decide to get immersed in a virtual environment and experience these benefits in dynamic, everyday contexts, such as in a car, the user has to be willing to give up their situation awareness about the real world. By accurately understanding users' perceptions of risks involved in the adoption of VR in a car, or other dynamic real world environments, we can better understand the behavior of users and mitigate risk perceptions to improve technology adoption [85]. In this study, we focused on users' perceived psychological risk and how the provision of information about the real world in the virtual influence this risk domain, perceived workload, and situation awareness. We were also interested in the effect of vehicle automation level on users' VR in car experience, since the advent of fully automated vehicles will allow passengers to engage in increasing immersive experiences [66], while introducing different perceived risks than human-driven cars [20]. In the following section, we reflect upon our findings from the collected data, address the research questions, and provide theoretical explanations for our results.

5.1 Effect of Vehicle Automation Level

Participants demonstrated significantly higher affective perceived risk in the *FAV* condition than in the *HDV* condition. In other words, they *feel* that there may be unpleasant things that can occur more frequently while using VR in an fully automated vehicle, which may cause their higher scores on affective perceived risk. However, there was no significant effect of automation level on participants' PxS scores; they *think* the probability of catastrophic events and the severity of them happening is not different between an fully automated car and human driven car. These results suggest participants may not feel safe in fully automated vehicles yet, but are aware of their improved capabilities compared to a human driver. The data collected from the interviews confirms these findings, as some participants pointed at the disunity of their logic and emotions with regards to fully automated cars. This is consistent with the existing literature, as other studies have also indicated people's hesitation to relinquish control to automation due to lower trust levels [73–75].

5.2 Effect of SA Cues

Participants' perceived workload was significantly lower if they received SA cues during their rides. However, the SA cues are an additional source of information that the participants need to perceive and process. In other words, the SA cues may compete with the VR content for the limited resources of mental processes [6], and therefore lead to higher workload. Hence, one may expect that the *Cue* condition is associated with higher workload. The results show the opposite of this effect, with the *Cue* condition leading to a significantly lower workload. One possible explanation for this observation lies in the fact that workload and SA could both compete with each other or support each other [89]. On one hand, frequent sampling and updating information to maintain situation awareness could lead to higher workload. However, In the case of our experiment, the SA cues seem to support a more efficient use of resources, thereby producing a lower level of workload. Keeping the participants in the loop about the dynamic real world through the cues may prevent the participants from searching for this information themselves, and thus free their processing resources, leading to lower perceived workload.

Lack of statistically significant effects of the SA Cues on situation awareness was surprising, since users' awareness of the real world was expected to be impacted by the provision of information about the real world. The data from the interviews shed some light on why the results did not show a significant effect of SA Cues on situation awareness: while some participants believed they were helpful, others expressed their lack of interest in receiving them, and hence, making the total effect of SA cues negligible. However, the SA cues significantly decreased participants' perceived workload, signifying the benefit of receiving this information for participants, even if they did not consciously appreciate it. The literature also suggests that the communication between the user and an AI system can improve users' trust towards the system through the information it conveys [18, 39, 50].

6 Limitations and Future Work

There are naturally some limitations to the study that we conducted. One constraint is the difference between the simulation and real-life driving, though this is likely modest since the participant was a passenger (not a driver), the driving simulator includes a complete car, there are wrap-around visuals, audio cues, and vehicle motions cues. Nevertheless, the lack of statistically significant effects of SA Cues on perceived risk may be due to the nature of conducting the experiment in a driving simulator, since it may not convey the exact same amount of perceived risk as a real car [8]. Future studies will investigate the use of VR in cars and the role of situation awareness in a real car for a more accurate inclusion of the dynamic real-world environment. Also, while our participant sample did range from 18-46 years old, it was somewhat skewed towards young, technologically proficient students. Hence, it will be interesting to replicate this study with participants with a broader technology proficiency and older populations, as these are important factors affecting users' risk perception, VR immersion, and attitude towards technology in general [3, 59, 78]. Future research could also investigate users' informational needs in VR when engaging in active tasks, or tasks of different types, such as productivity and relaxation. The results in this paper are pertinent to SA cues that are delivered saliently; future research could also include an investigation of ambient delivery of SA cues and its effect on users' experience.

7 Conclusion

The use of VR in dynamic real-world environments such as in cars has recently received attention from both academia and industry. The benefits of studying the use of VR in cars is not limited to this context. It can help in the understanding of the use of VR in other on-the-go real world contexts such as buses, planes, or trains [58]. Moreover, one can view the use of VR in cars as an extreme use case and transfer the findings to other dynamic real world contexts such as work from home, when there are other people in the environment, kids running around, door bells ringing, etc. [22]. However, for these use cases of VR devices to become prevalent, users' perceived risk of this situation has to be extensively studied and minimized. In this study, we focused on users' perceived psychological risk and how the provision of information about the real world affects users' VR experience, while riding in a fully automated and a human-driven car. The results of the study, conducted in a motion-platform driving simulator, reflect users' vigilance with VR and the novel FAV technology that is not yet ubiquitous. Interestingly, exposure to the cues was related to lower, rather than higher, perceived workload. Thus, although increasing the amount of information the participants had to process, the cues reduced their need to actively seek this information on their own, thereby lowering their workload. This study provides valuable insights into passengers' experience and sheds light on their information needs while immersed in VR environments. Identifying passengers' unique challenges and needs, as well as developing solutions for them, is expected to improve users' travel experience and move the industry towards a wider adoption of VR devices.

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