Unintentional Costs of Vehicle Warning Modality for Driving Hazards

by

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ABSTRACT

Proper allocation of attention while driving is imperative to driver safety, as well as the safety of those around the driver. There is no doubt that in-vehicle alerts can effectively direct driver attention. In fact, visual, auditory, and tactile alert modalities have all shown to be more effective than no alert at all. However, research on in-vehicle alerts has primarily been limited to single-hazard scenarios. The current research examines the effects of in-vehicle alert modality on driver attention towards simultaneously occurring hazards.

When a driver is presented with multiple stimuli simultaneously, there is the risk that they will experience alert masking, when one stimulus is obscured by the presence of another stimulus. As the number of concurrent stimuli increases, the ability to report targets decreases. Meanwhile, the alert acts as another target that they must also process. Recent research on masking effects of simultaneous alerts has shown masking to lead to breakdowns in detection and identification of alarms during a task, outlining a possible cost of alert technology. Additionally, existing work has shown auditory alerts to be more effective in directing driver attention, resulting in faster reaction times (RTs) than visual alerts. Multiple Resource Theory suggests that because of the highly visual nature of driving, drivers may have more auditory resources than visual resources available to process stimuli without becoming overloaded. Therefore, it was predicted that auditory alerts would be more effective in allowing drivers to recognize both potential hazards, measured though reduced brake reaction times and increased accuracy during a post-drive hazard observance question.

The current study did not support the hypothesis. Modality did not result in a significant difference in drivers' attention to simultaneously occurring hazards. The salience of hazards in each scenario seemed to make the largest impact on whether participants observed the hazard. Though the hypothesis was not supported, there were several limitations. Additionally, and regardless, the study results did point to the importance of further research on simultaneously occurring hazards. These scenarios pose a risk to drivers, especially when their attention is allocated to only one of the hazards.

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CHAPTER 1

OVERVIEW

Driving requires humans to constantly disperse and switch their attention between multiple tasks at any given time, known as sequential multitasking (Salvucci et al., 2011). Drivers must monitor the environment surrounding them, maintain a specific speed limit, remember directions, and react to the actions of other drivers. As each of these individual tasks adds to the driver's overall cognitive load, they become increasingly demanding, leading to safety concerns and potential cognitive overload. In addition to these ongoing tasks, drivers often experience unexpected distractions on the road or within the vehicle. Due to the unexpected nature of these additional demands on attention, it is important that a vehicle's design, specifically its hazard alert system, effectively supports drivers' needs to switch their attention at any given moment and allow them to focus on what is most important in their environment.

In-vehicle alerts can assist drivers in detecting potential hazards and allowing them to react faster and maintain greater overall situational awareness, defined by Gugerty (2011) as an understanding of the state of their environment. The development and advancement of vehicle technologies based on LIDAR and radar signals have allowed for many of these unexpected distractions to be communicated to the driver through the onset of a warning signal inside the vehicle. Previous work has identified auditory, visual, and tactile alerts to all be more effective in warning drivers of potential hazards than no alert at all (Ho et al., 2005; Ho et al., 2007; Scott & Gray, 2008). However, most of the research on in-vehicle alerts has investigated singular alerts and hazards. This has created a gap in knowledge, specifically about the effects of alerting across multiple hazards, especially when these alerts are presented in a short time span or simultaneously (Wan & Sarter, 2022).

Two of the most important elements involved in filling this gap relate to alerts in general, and to attention in multitasking. For example, though alerts can help direct driver attention, they also require attentional resources from the driver. Therefore, it is essential that they are salient enough to capture the driver's attention, without entirely distracting them from other tasks and potential hazards. At the same time, any task or event occurring at the same time as another will challenge the driver to select the best task to allocate attention to, and this likely creates a problem because of limited attentional resources. Interestingly, both main issues can be viewed through yet another lens of alert study, which is the modality in which the alert occurs; the modality choice of an alert may or may not further interfere with other alerts, or the task itself.

Therefore, in the next several sections, a common theory of multitasking (Multiple Resource Theory) is discussed, along with theories regarding information processing of alerts, and alert saliency and modality, moving steadily toward applying them in conjunction with hazard recognition in the driving domain.

MULTIPLE RESOURCE THEORY

Wickens's Multiple Resource Theory describes the limited amount of attentional resources humans have for processing information. When a person attempts to attend to multiple tasks concurrently, known as time-sharing, they are most effective when the tasks fall on different resources, which can take the form of codes, or modalities. Multiple Resource Theory may also be beneficial in predicting the cognitive load that one might experience as they are switching between tasks (Wickens, 2008). In the context of the current research, if a person were to attempt multiple tasks in the visual modality, they would be less effective in their time-sharing than if they were to attempt one task in the visual modality and the other task in the auditory modality. They would also be less likely to experience overload and thus performance decrements, as they would have sufficient attentional resources to allocate towards each task.

Multiple resource theory is relevant in driving in part because the tasks performed during driving are intensely visually demanding (Sivak, 1996), meaning that there is high resource overlap, and drivers may not have excess visual attentional resources to use. Further, greater mental load during driving can be brought on by these conflicts, and, is known to increase or lead to inattentional blindness, higher error rates, and reduced target detection, all of which have dangerous implications (Recarte & Nunes, 2003). The effects of cognitive load while driving are also thought to be more prominent when drivers must complete actions that are not automatic to them (Engström et al., 2017); while some hazard detection and avoidance may become familiar with increasing experience.

Alternatively, if a modality that is not in high demand is required in a task, the driver may still have resources available that allow for completion of a task and successful avoidance of overload (Wickens, 2008). Therefore, drivers may have spare auditory attentional resources that can be allocated towards unexpected tasks, such as observing and reacting to a sudden road hazard alert, without putting them at the same risk for overload and with lowered potential to create interference costs. In fact, many alarm and alerting systems are designed with these primary elements in mind; and it also explains why texting and driving is particularly dangerous as it requires the same visual resource (Caird et al., 2014).

Though drivers do not experience constant cognitive overload, the unexpected nature of many hazards means that they could experience it at any given time, and the ongoing load on them may vary. A driver may be able to effectively react to a single alert or hazard appropriately, but attentional demands become much higher as the number of stimuli they must observe in a short timespan increases (Wan & Sarter, 2022). Further, the presence of a single hazard does not mean others are not present or emerging in the environment. The multi-hazard problem presents a unique case in which the limits of attention are particularly strained: drivers have to detect and mitigate multiple concurrent events. Any alerts or alarms to help them with this task would appear to aid early detection and attention orienting as a first step. Therefore, it is important that the effects of alerting to concurrent hazards are well understood as vehicle alert systems continue to evolve so they may appropriately guide driver attention without overloading them.

ALERT MODALITY

Research studying the salience of auditory and visual alerts has shown auditory alerts to be more salient, and therefore more effective in directing both auditory and visual attention. Auditory alerts have RT benefits for not only auditory targets, but targets in different modalities (Driver & Spence, 2004; Spence, McDonald, & Driver, 2004; Wickens, McCarley, & Gutzwiller, 2022). Auditory alerts are also audible from greater distances than visual alerts are visible from and importantly do not require operators to scan instruments (Doll & Folds, 1986). Of critical impact here is that auditory alerts have been shown to be more effective than visual alerts in directing attention towards hazards as well as shortening reaction times while driving (Scott & Gray, 2008; Lee et al, 2002). In these cases, two things should be pointed out: (1) the benefit of any alarm is usually better than none, and (2) these studies tend to examine singular hazard events in time, rather than co-occurring or overlapping hazards.

Although auditory alerts may be better than visual in the visually demanding driving environment, there is extensive evidence on auditory stimuli's ability to involuntarily interrupt selective attention (Parmentier, 2008). Due to their salience, auditory alerts are known to be more disruptive and have the potential to capture attention and pull it away from a higher priority task, also referred to as auditory preemption (Proctor & Proctor, 2006; Wickens, McCarley, & Gutzwiller, 2022). The cueing benefits of auditory alerts also last longer when the cues are predictive of a target. Once cued by an alert, people may find it difficult to divide their attention between different locations due to the spatial links between auditory and visual attention (Spence & Driver, 1997; Spence et al., 2000; Wickens, McCarley, & Gutzwiller, 2022). Additionally, auditory alerts may be less effective in indicating the direction of a hazard (unless presented using directional audio equipment or headphones), and they have a greater potential for driver annoyance (Marshall et al., 2007).

Visual alerts, on the other hand, may be more likely to be impacted by inattentional blindness, causing drivers to miss the onset of an alert - even when it is presented in their central vision (Herslund & Jorgensen, 2003). Visual alerts may also pose the risk of masking other important visual information in an environment, such as the potential hazard needing attention in the first place (Maltz & Shinar, 2003). There is also evidence that the modality of a secondary task changes how drivers allocate attention during dual tasking. For example, when required to complete a secondary visual imagery task, drivers had less saccades and fixations to the mirror and speedometer in comparison to a verbal task, suggesting a potential decrease in environmental perception (Recarte & Nunes, 2000). In driving alert research, visual alerts have also resulted in longer reaction times compared to auditory or tactile alerts (Maltz & Shinar, 2004; Scott & Gray, 2008), and generally auditory interrupting alerts are faster (Sarter et al., 2013). Further visual attentional interference has been shown in flight simulator research in which head-up displays (HUDs) which overlay visual information on the environment can lead to longer reaction times than traditional flight instruments when detecting hazards on a runway (Fischer, 1980), sometimes missing them altogether. There is additional risk that visual alerts may be lost amongst other lights and clutter in the visual periphery (Nikolic et al., 2004). When considering alert implementation, the salience of each must be strongly considered, balancing salience with annoyance or distraction. Auditory and visual alerts both have benefits and drawbacks related to their salience; the consideration of these factors in the context in which they will be used is key to ensuring their effectiveness.

ATTENTIONAL BLINK AND ALERT MASKING

A risk involved with attention-demanding alerts is the potential for a distraction away from other occurrences requiring the driver's attention. In the current research, this could mean a driver attending to one hazard could result in them missing another. The co-occurrence problem invokes the attentional blink phenomenon wherein, when two stimuli are presented 200-500ms apart, there is difficulty detecting the second stimuli due to a temporal delay of attention after processing the first (Raymond et al., 1992). In support of attentional blink occurring in driving scenarios, there is evidence that when presented with multiple hazards simultaneously, drivers' hazard detection accuracy decreases (Sall & Feng, 2019). This effect can also be seen in the reverse direction, when a secondary stimulus in a series causes the person to miss the first stimuli, called backwards masking (Wan & Sarter, 2022).

SITUATION AWARENESS

Situation awareness as "an understanding of the state of the environment" and "the primary basis for subsequent decision making and performance in the operation of complex, dynamic systems" (Endsley, 1995). Gugerty (2011) added to this definition, considering the crucial role of situation awareness in driving, defining it as "the updated, meaningful knowledge of an unpredictably-changing, multifaceted situation that operators use to guide choice and action when engaged in real-time multitasking". Specifically, Gugerty describes situation awareness in three levels: the first being automatic processes using little to no cognitive resources, the second being brief periods of consciousness, and the third level of SA being highly cognitively demanding conscious processes. Situation awareness in driving may present itself through ambient processes and peripheral events, task management, focal vision processes, and attention allocation.

Situation awareness' relationship to driver attention is critical for understanding and measuring hazard observance. Effectively measuring driver attention can aid in gauging how their attention changes as they encounter hazards. In driving, situation awareness can be measured by both online (while driving) and offline (post-driving) measures. In the current experiment, situation awareness was considered in the design of hazard observance measurements through both online (reaction times and steering direction) and offline measures (post-drive hazard observance questions). Originally described by Endsley (1995) as imbedded task measures, and demonstrated in the context of driving by Gugerty and Falzetta (2005), event detection through performance-based measures records implicit awareness through drivers' reactions (ideally avoidance) to a hazard. This method can mitigate memory problems caused by other situation awareness measures that rely on recalling knowledge (Gugerty, 1997; Gugerty, 2011; Gugerty & Falzetta, 2005).

CURRENT RESEARCH AIM

There is a gap in research on the effects of in-vehicle alerts on these simultaneously occurring hazards in driving scenarios. At an initial glance, scenarios in which two hazards occur simultaneously may seem unlikely – yet at least a handful of impactful real-world conditions create such a scenario. An example of such a scenario may include making a right turn at an intersection when there is another car turning left into the same area (hazard 1) and a pedestrian is crossing the crosswalk (hazard 2), changing lanes on a busy highway where one must monitor both the area in front of their car for braking (hazard 1) and their blind spot simultaneously (hazard 2), or driving in a parking lot where any number of cars could be a hazard.

Knowledge of how attention towards driving tasks is affected by the modality of in-vehicle hazard alerts is critical information for designers of current and future vehicle interfaces. The current research aims to understand the impact of in-vehicle alerts and modality on driver attention towards a simultaneously occurring (but not alerted) road hazard, measured using brake reaction time, and awareness measures of the hazard in a situation awareness-type assessment. Additionally, the driver's self-reported trust in the alert system, and experience with driving and alert systems will be evaluated to identify any confounding effects.

It is hypothesized that the alert modality (visual, or auditory) will impact the participant's brake time to the hazard, and their verbal account of the trial. Specifically, consistent with Multiple Resource Theory (Wickens, 2008), it is hypothesized that the auditory alert condition will result in earlier brake times and more accurate verbal observance of both hazards, due to the greater availability of auditory attentional resources while driving.

CHAPTER 2

CURRENT STUDY

PARTICIPANTS

The study used a between-subjects design to study the effects of alert modality on participants' observations of simultaneously occurring hazards and their trust in the alert system. Participants consisted of 23 undergraduate students from the Arizona State University HSE 101 subject pool. Participants were compensated for their time with one research credit for one hour of participation.

Before participating in the study, participants provided informed consent [Appendix A]. To take part in the study, participants were required to have a valid driver's license, speak English, and have normal or corrected vision. In addition, they were required to complete a motion sickness prescreening before participating; students with a history of motion sickness were not eligible to participate. Participants also completed a test drive to ensure comfort in the driving simulator before beginning the experiment [Attachment B].

MATERIALS

The study used a DriveSafety driving simulator, located on the Arizona State University Polytechnic Campus. During the study, participants sat in the front half of a Ford sedan. Three TV monitors were displayed in front of the car to simulate the driving environment, in addition to screens in the rear-view mirror and both side mirrors (see Figure 1).

Drive Safety's Hyperdrive software was used to design and program the simulator drives. The simulator software also collected brake time, brake pressure, steering direction, and time to collision data during each trial, which were used as study measures. The lights in the simulator room were kept off during the entirety of the drives.

FIGURE 1

DriveSafety simulator

Before the study, participants were asked to complete a motion sickness pre-screen. They were then provided with their participant code, which allowed them to participate. Upon arrival, they were briefed with the experiment instructions [Attachment C] before consenting [Appendix A] and being asked to complete a survey about their driving and in-vehicle alert experience [Attachment D] , as well as a 12-item survey [Attachment E] evaluating their trust in the alert system (a modified version of the Jian et al. 2002 "Trust in autonomous systems scale"), administered again after completion of the trial drives.

After each task trial, the simulator's drive scenario was removed from the screen before participants were asked to describe the drive they just completed, focusing on any important details, problems, or safety hazards they encountered [Attachment F]. The first time the question was asked, participants were also given an example answer. The study facilitator typed participants' verbal responses while they remained in the simulator cab.

PROCEDURE

Participants were randomly assigned to one of two alert conditions, auditory or visual. The auditory alert consisted of three short 1846 Hz tones through the simulator speaker system, on the higher end of the range recommended by NHSTA (Jeon et al., 2022). This alert was selected to signify urgency, while remaining detectable for drivers. The visual alert consisted of an image of a red octagon flashing 3 times on the simulator screen. The octagon was 300 x 300 pixels, and it was confirmed that it did not block any of the hazards as they occurred. The semantic meanings of the two alerts were balanced and were meant to alert participants without giving them specific directions. Each alert occurred at the same time as the hazard was presented.

After giving their informed consent, participants completed a driving experience and trust questionnaire. Participants then completed a practice drive, free from hazards and alerts, to ensure they did not experience motion sickness and felt comfortable operating the simulator. They then completed two trial drives in their assigned alert condition. The drive order was randomly assigned and counterbalanced to control for any learning effects that occurred across multiple trials.

Each drive contained one hazard scenario, in which two simultaneously occurring hazards were presented to the driver. In the scenario one drive, a pedestrian runs out from behind a semi-truck on the driver’s left side, while a driver unexpectedly pulls out from a driveway on the driver’s right (see Figure 2). In scenario two, a car begins to back out of a parking space on the driver’s left, while a car on the driver’s right quickly pulls in front of the driver (see Figure 3).

FIGURE 2

Scenario one hazards: pedestrian hazard on left, black car hazard center

FIGURE 3

Scenario two hazards: blue car hazard closest to driver on left, yellow car hazard on right

Several participants also noted a pedestrian in the second scenario, though this was not considered a hazard in the scoring, as it did not pose imminent danger of any collision and could be ignored.

During the drive, verbal directions were provided by the study facilitator (instructions on turns, for example). After each drive, participants were asked to describe the drive they just experienced, reporting any important details, safety hazards, and problems experienced during the drive. Participants' brake reaction time, brake pressure, and steering direction were also collected through the driving simulator as a measure of hazard observance. Upon completion of the final drive, participants were asked to complete the 12-item alert-system trust survey again.

Participant brake RTs were calculated using drive data recorded in the simulator. The time of the hazard onset was subtracted from the time that the participant began applying the brakes to determine the difference.

CHAPTER 3

RESULTS

Data for one participant was excluded from all analyses due to a technical malfunction in the driving simulator where the hazard was not displayed. RT data was excluded for two other participants, one of which applied their brakes before the hazard onset and continued to brake throughout the remainder of the scenario; the other did not brake at all during the hazard scenario. Data for these participants was still included for other analyses as they experienced, and verbally responded to the hazards normally.

Due to technical difficulties with the driving simulator, hazard onset data necessary for calculating RTs for the scenario two drives was not collected, resulting in the inability to accurately analyze and compare the reaction times for scenario two.

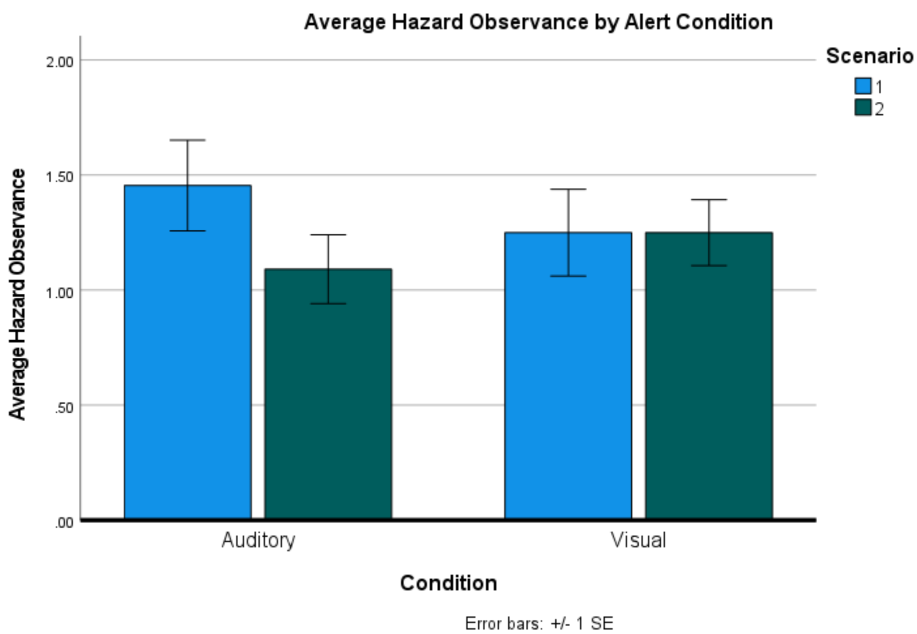
SITUATION AWARENESS

A 2x2 mixed analysis of variance (ANOVA) was used to evaluate whether there was a significant effect of the alert modality (audio, visual) and driving scenario (S1, S2) on driver hazard observance. Because there was not a significant effect of counterbalancing the drive order, it was removed in further analysis of SA. Analysis of the results revealed that there was not a significant effect of alert modality on verbal hazard observance, $F(1, 21) = .014$, $p = .907$. Additionally, there was no effect of drive scenario on verbal hazard observance, $F(1,21) = 1.511$, $p = .233$, and no interaction of drive scenario and alert condition, $F(1, 21) = 1.511$, $p = .233$ (see Figure 4). Analysis of

Cohen's *d* displayed relatively small effect sizes for S1 and S2 hazard observance, .313 for scenario one and .321 for scenario two.

FIGURE 4

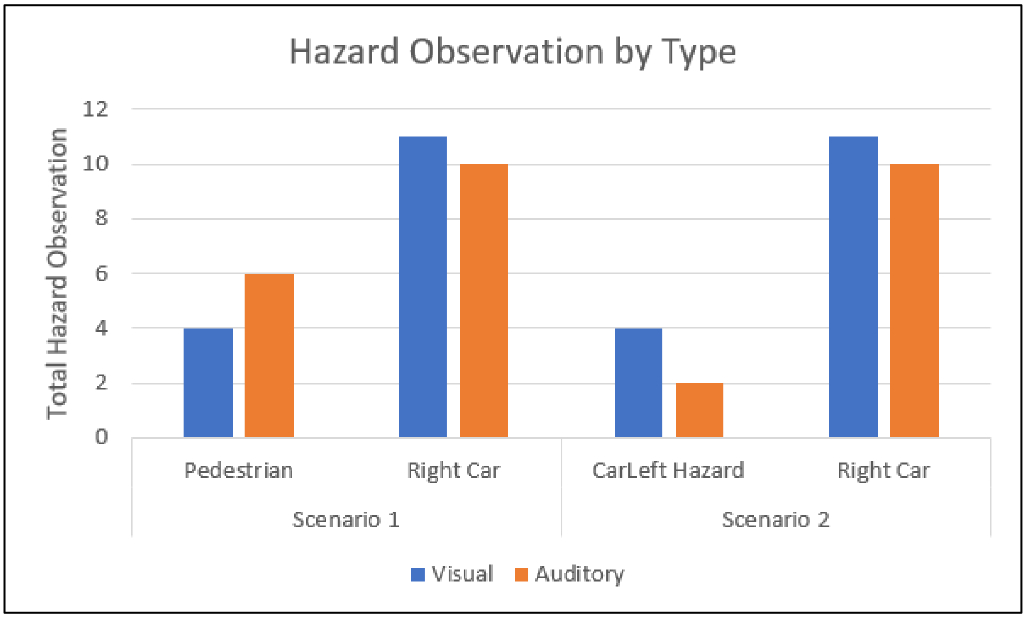
Hazard observation by alert condition



Although the combined SA measures did not reveal differences in condition or order, a breakdown of type of hazard does reveal an interesting pattern (see Figure 5).

FIGURE 5

Hazard observation by hazard type



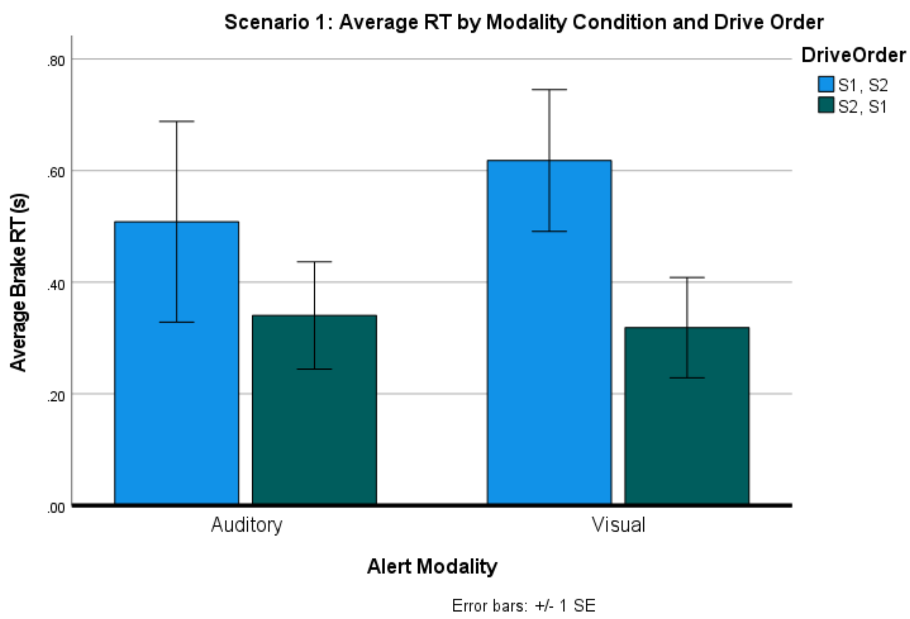
In scenario one, the car pulling out of the driveway on the right was recognized by nearly all participants, whereas the pedestrian on the left was observed by only 10 participants. In scenario two, almost all participants also observed the vehicle pulling in front of them from their right side, but only 6 noticed the second car hazard pulling out on their left. One potential explanation (expanded on in the Discussion section) is that these hazards are particularly salient; but in either case, this data does seem to reveal that experiencing more than a single hazard simultaneously means one of them is likely to be missed.

REACTION TIME

Using a two-way ANOVA, the effects of modality condition and drive order on brake RTs for scenario one were analyzed (see Figure 6). Counterbalancing drive order also did not result in a significant effect, and was removed before further analysis. No significant effects of condition were found, $F(1, 19) = .118$, $p = .735$. A Cohen's d of .151 indicated the small effect size of the findings.

FIGURE 6

Average RT by alert condition and drive order



DRIVING EXPERIENCE

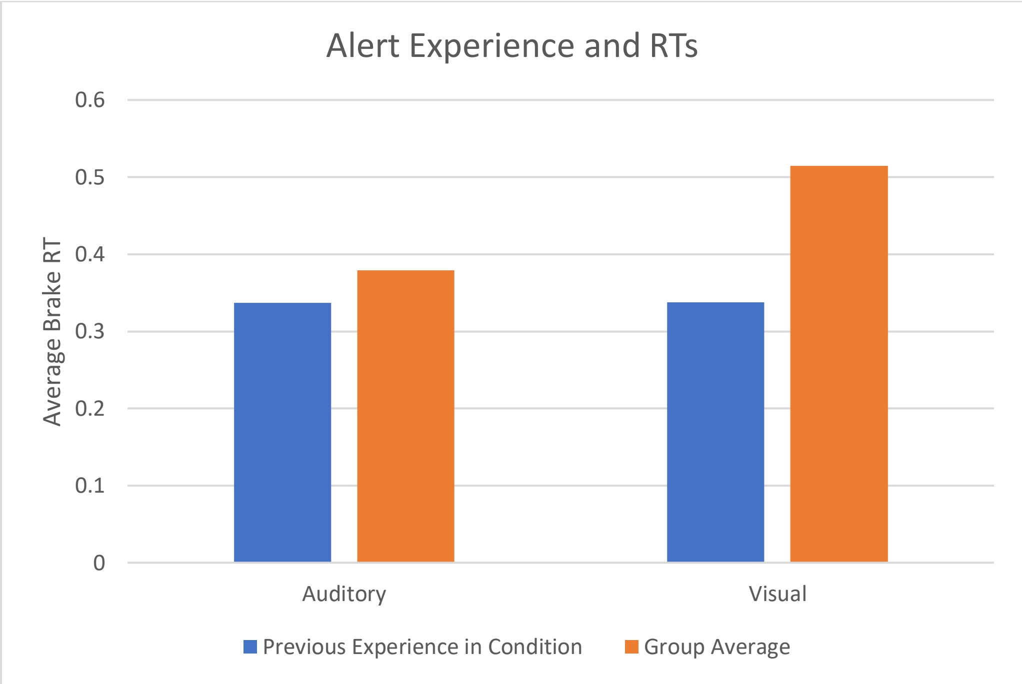
The average driving experience for participants was 4.63 years (Min years = 2, Max years = 15, SD = 2.94). However, it was noted that one participant reported additional driving experience because they began driving with their parent at the age of 11.

Participants also reported their experience with alert systems prior to the drives. Most experience was with auditory alert systems (11), followed by visual (8), and tactile (6). One participant also reported experience with steering assist. Exploratory ANOVAs including driving experience as a covariate factor for SA and RT dependent measures failed to show that driving experience impacted participants' RTs, $F(1, 19) = 3.292$, $p = .086$, or hazard observance, $F = (1, 21) = 4.057$, $p = .058$. A Cohen's *d* analysis showed a relatively small effect size of .388.

To better understand the findings of the RT data, it was speculated that prior experience with these alerts may alter reaction times. Experience using an alert provides an expectancy for top-down attention allocation. In (see Figure 7), when participants have previous experience with the modality of the condition they were assigned to, they displayed shorter RTs than the rest of the condition group. The average RTs for the visual and auditory conditions with prior experience were almost equal. In attempting to determine why the alert condition manipulation had no effect on RT, this may explain that experience or familiarity with the alert type impacted RTs.

FIGURE 7

Impacts of previous alert experience on RT



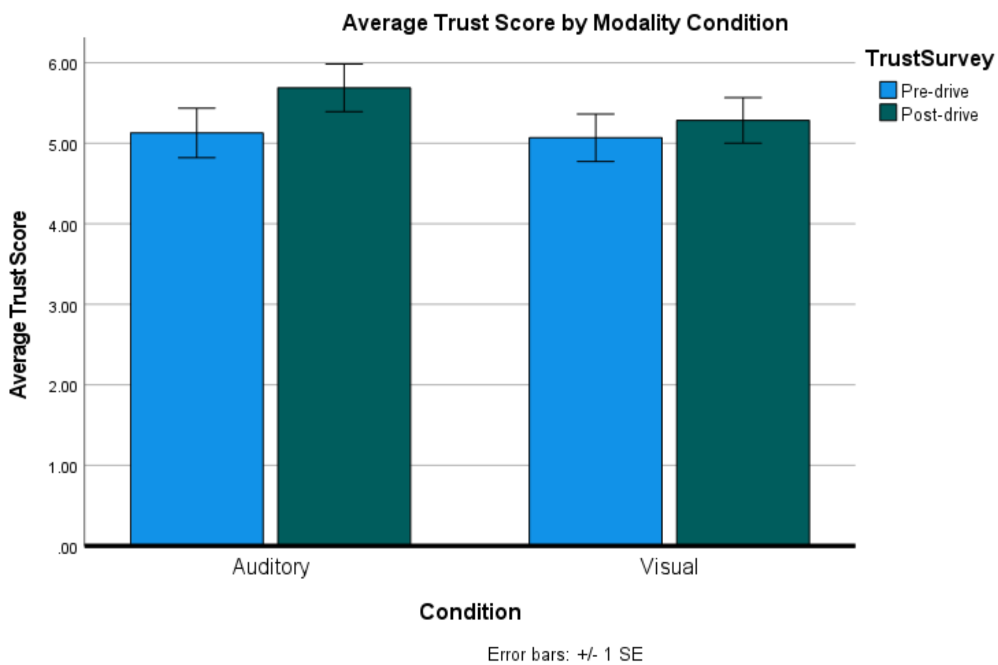
TRUST SCORES

Pre-drive trust responses resulted in an average score of 5.11 out of 7, with the auditory group's initial trust score as 5.13 and the visual group's initial trust score as 5.07. The post-experiment trust scores showed an average score of 5.5, with the auditory group's score as 5.69 and the visual group's score as 5.28. It is important to note that the groups were not aware of their alerting condition when completing the pre-experiment questionnaire. Significant effects were found in participants average trust scores, showing that their trust increased after interacting with the simulator, $F(1,21) = 4.751$, $p = .041$.

Cohen's *d* showed an effect size of .058 for the pre-drive trust responses, while post-drive responses showed an increase in effect size to .414.

FIGURE 8

Average trust score by alert condition



CHAPTER 4

DISCUSSION

OVERVIEW

The current study findings did not support the research hypothesis, or previous findings related to auditory and visual hazard alerts (Ho et al., 2005; Liu, 2001; Scott & Gray, 2008; Wan & Sarter, 2022). There was no effect of alert modality found on either measure of hazard observance (verbal responses, or brake RTs). This result may have been impacted by the small sample size, lack of RT data for Scenario two, the experience with alert systems, and the varying difficulty of each scenario. Each dependent variable displayed relatively small effect sizes for all measures, validating the need for a larger sample size.

SALIENCE OF HAZARDS

In exploratory analyses, it was discovered that each hazard appeared to be recognized at very different rates. One explanation for this may have been hazard salience. In driving, not all hazards are equally salient. Some road hazards are easier to detect than others due to precursor cues that may alert the driver to a potential hazard (Crundall et al., 2012), or because they contain attributes of greater visual salience, such as abrupt onset of the hazard, or strong contrast between the hazard and its environment (Wickens, McCarley, & Gutzwiller, 2022). On the other hand, hazards obscured by the environment, such as a pedestrian behind a truck, or hazards immersed in more cluttered displays (especially those that contain homogenous stimuli, such a car parked amongst many other parked cars) are more difficult to detect, especially for drivers with less experience (Crundall et al., 2012; Ho et al; 2001; Wickens, McCarley, & Gutzwiller, 2022). In both scenarios, one of the two hazards was more likely to go unnoticed by the participant, and it is worth pointing out drivers *did* tend to notice the more central and right-side hazard more often. This may indicate that the salience of the hazard played a role in whether the hazard was detected.

The pedestrian hazard displayed in scenario one may have been slightly more salient to drivers, as it was closer to their focal field of view and occurred at a higher speed than the secondary hazard in scenario two. In scenario one, the car pulling out of the driveway on the right was identified as the higher salience hazard, resulting in a greater number of observations from participants than the pedestrian on the left. In the second scenario, most participants also observed the vehicle pulling in front of them from their right side but far less observed the second car hazard in the parking spot to the left of them. This may have been due to the positioning of the car in the parking spot, as it was placed further away from participants' focal field of view. Due to the differences in visual acuity in focal and peripheral vision, it has been shown that stimuli in driver's peripheral vision are more likely to go unnoticed, or result in greater RTs (Nikolic et al., 2004; Summala et al., 1998). Interestingly, the visual alert condition displayed slightly (but not significantly) higher accuracy than the auditory condition in this scenario. This may have been due to the visual alert broadening their field of view in terms of attention allocation, although this is difficult to determine.

Another feasible explanation for the findings on SA could be the effects of attentional blink causing participants to miss the second, potentially less salient hazard, due to their attentional process being engaged in another task (observing and reacting to the more salient hazard). Consistent with Raymond, et al.'s (1992) explanation of attentional blink, the two hazards, presented in close temporal proximity, result in an inability to detect a second hazard in close to half of the drives in both scenarios. Furthermore, the salience of the hazard seemed to impact which hazard participants observed and their overall SA accuracy. A similar attentional blink phenomenon was found in high versus low hazard salience in driving scenarios by Sall and Feng (2019), in which there was a significant difference in participant's detection of high-salience hazards in comparison to low-salience hazards. Though salience was not the primary focus of the current research, its potential role in the results indicates its importance in drivers' ability to detect simultaneously occurring hazards. In future studies, it would be interesting to consider hazard salience as factor, looking at whether SA averages are impacted when the two hazards are judged to be equally salient, versus when one hazard is more salient than the other.

There is not a clear theoretical connection between attentional blink and Multiple Resource Theory in the current results. However, another possible explanation for the lack of significant difference of alert modality on RT and SA, and even the slightly greater awareness of the less salient car hazard in scenario two, could be auditory preemption. Auditory preemption is the ability for an auditory alert to "capture and demand attention at the expense of the ongoing task" (Wan & Sarter, 2022, Wickens et al., 2005). The benefits of auditory alerts in driving suggested by Multiple Resource Theory may have been overshadowed by the auditory alert's attention capture abilities, resulting in a slight cost of hazard observance (Wickens et al., 2005). However, if this were the case, it would be difficult to explain why the phenomenon only appears for one of the two scenarios and not overall.

EFFECTS ON TRUST

There was a significant effect shown between pre- and post-drive trust scores across both conditions, indicating that participant's experience with the alert system resulted in greater rankings of trust in the post-drive questionnaire. A few factors may have accounted for this, as 14 of the 23 participants reported previous experience with some type of alert system, the majority of experience being with auditory alerts followed by visual alert systems. Furthermore, 10 participants were assigned to a modality condition where they had previous experience with the alert modality they were assigned to. Because of their previous experience with the alert condition or an alert system in general, after they'd experienced the alert system in the study, these participants may have felt a greater sense of familiarity with the alert system when completing the post-drive trust questionnaire.

Because participants were blind to their assigned condition when completing the pre-drive trust questionnaire, they may have felt slightly skeptical of the alert system or greater uncertainty because they would not have known whether they had previously interacted with a similar alert system. After gaining experience with the alert system or likening it to an alert system they'd experienced before, their overall trust and familiarity in the system may have increased. This is supported by previous research in which driver trust has significantly increased after participants' initial experience with the driving simulator (Hartwich et al., 2019; Kraus et al., 2019)

LIMITATIONS

Potential limitations of the research include those related to the participant group. The limited number of participants in the subject pool resulted in a small sample size. Additional research with a greater number of participants and scenarios should be conducted to further investigate the findings of the current study. Completion of additional drives may help to balance learning effects with additional experience in trials, and it may also help increase the chance that each hazard is equally salient.

The participant pool used limited insights into how alerts may impact different ranges of driving experience, given that many participants were college freshmen with relatively low driving experience. Greater driving experience can be especially helpful in developing effective visual search strategies and mental models used to identify and mitigate road hazards. Previous research has shown that drivers with greater driving experience display shorter RTs, broader visual scanning, and are more likely to fixate on potential hazards than drivers with less experience (Crundall & Underwood, 1998; Crundall et al., 2012; Konstantopoulos et al., Upahita et al., 2018). Therefore, it would be helpful to consider groups with greater driving experience and potential differences in how they observe and react to simultaneously occurring hazards.

In future studies, inclusion of a control group would be greatly beneficial in order to assess whether our alerts themselves were more effective than no hazard at all, as found in previous research (Ho et al., 2005; Scott & Gray, 2008). Such a control would also allow for a better understanding of trust differences over time in alert systems, since it could be that trust was influenced by factors like familiarity in the simulation.

Although the alerts in the current study were matched across auditory and visual conditions for their semantic meaning, cross modal matching was not performed, as recommended by Pitts et al., (2015). Due to the large variability in which individuals experience alerts, there is a need to determine an average when matching hazards of different modalities for salience, specifically matching for loudness and luminance for auditory and visual alerts. Using cross modal matching helps mitigate the possibility of experimental confounds due to differences in the salience of alerts. Explicitly validating alert salience equivalency before implementing them would ensure that both alert conditions are equally salient. However, that does not guarantee that the hazards themselves would be equivalent as mentioned before.

Finally, although questions from the Jian et al., (2000) trust survey were intended to be randomized to mitigate potential bias due to the order of the questions (Gutzwiller et al., 2019), difficulties with the survey platform prevented this despite repeated testing during study design. Further research using the Jian trust questionnaire should ensure its randomization.

CONSIDERATIONS FOR FURTHER RESEARCH

Additional research should be conducted to further understand the impacts of alert modality of drivers' hazard observance, particularly to understand how attention is impacted at a wider variety of speeds and driving environments, such as highway or rural roads. Further research on simultaneously occurring hazards including other modalities, such as tactile alerts or multimodal alerts, could aid in furthering the understanding of their impact on driver attention, allowing vehicle manufacturers to make informed decisions on the ideal hazard alert to direct driver attention without the potential to distract away from other hazards. Previous research has also indicated the benefits of directionality in alerts, showing that spatial collision alerts result in shorter RTs and greater SA (Beatty et al., 2014; Chen et al., 2020; Ho & Spence, 2005). This may be another consideration for future research.

GENERAL DISCUSSION

To better understand how vehicles can effectively alert drivers to hazards in a variety of scenarios, research should continue to study how driver attention is impacted when they must attend to multiple road hazards. In the current study, drivers' situation awareness varied by the specific context of each scenario, much like it might in different real-world driving environments. Currently, the majority of driving research is limited to single hazard conditions (Sall & Feng, 2019), though recent work on simultaneously occurring hazards has demonstrated the importance of further empirical research on the topic (Sall & Feng, 2019; Wan & Sarter, 2022). Continuing to evaluate how drivers' situation awareness changes with the dynamic environment around them is key to building a greater understanding of how in-vehicle alerts can be used to mitigate potential collisions.

Overall, the hypothesis was not supported by the results, showing little difference between the use of auditory and visual hazards in the two scenarios. Though there was not an impact of modality on drivers' hazard detection, the safety issue of detecting two simultaneously occurring hazards was emphasized by the current research. The two hazards in each scenario were not equally salient which is also the case in many real-world driving environments. The feasibility of designing drives made it difficult to implement additional simultaneous hazard scenarios, limiting the drives used in the study to ones that were fully avoidable with forward braking. Nonetheless, inattention to a second hazard still poses a risk of collision. Drives in which braking does not mitigate both potential hazards could pose an even larger risk, especially if the less salient hazard must be avoided in another way. Further research is needed to better understand these findings and how they may apply to a wider variety of participants and scenarios.

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APPENDIX A

INFORMED CONSENT

I am a student under the direction of Professor Robert Gutzwiller in the Department of Human Systems Engineering at Arizona State University. I am conducting a research study to investigate the effects of alert modality on driving hazards.

I am inviting your participation, which will involve completing 8 drives in a driving simulator, and is estimated to take around 1 hour. You have the right not to answer any question, and to stop participation at any time. Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, there will be no penalty, and credit or compensation will still be awarded. You must be 18 or older and hold a valid driver's license to participate in this study.

Your participation will be used to better understand the effects that vehicle warnings have on driver reactions to road hazards. There are no foreseeable risks or discomforts to your participation although some people may get motion sickness while driving in the simulator. If this occurs, you are free to stop, and if necessary you will be escorted to health services. **If you have a history of motion sickness you should NOT participate in this study.**

Your responses will be anonymous. The results of this study may be used in reports, presentations, or publications, but your name will not be used. If you have any questions concerning the research study, please contact the research team at: rgutzwil@asu.edu.

If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788. Please let me know if you wish to be part of the study.

By answering below, you are agreeing to be part of the study.

I understand and agree to be part of the study.

→

APPENDIX B

TRIAL DRIVE INSTRUCTIONS

Before we begin the actual experiment, you will complete a few test drives for you to acclimate to the simulator. If you begin to feel sick, stop the car completely and get out of the simulator immediately. You will still receive credit.

- One straight drive, and stop. (1 minute)
- One with some turns, and stop. (2 minute)
- Ask participant how they feel – if they are ready, then move to the actual experiment.

Now we will move on to the trial drives. Please follow the directions presented on the screen to the best of your ability. After your drive is over, please pull over, fully stop the car, and we will ask you some questions.

APPENDIX C

BRIEFING AND INSTRUCTIONS

We are studying alert systems to improve driving safety. You will begin by filling out a survey on your driving experience. After that, you will complete several trial drives. I may stop to ask you questions in between each drive.

If you begin to feel sick at any time, please bring the car to an immediate stop and quickly step out of the vehicle. Please make sure your cell phone is turned on silent.

APPENDIX D

DRIVING EXPERIENCE SURVEY

- How many years of driving experience do you have?
- Do you have experience with any driving alert systems?
- If so, what kind?
- Sound alert
- Visual alert
- Vibration alert
- Other (please specify how it appears to work to you, and the make/model of the vehicle you drive while using it)

APPENDIX E

TRUST QUESTIONNAIRE

The trust survey is a modified form of the one used in Jian et al. (2000) to measure trust in automated systems. The order of the questions will be randomized in Qualtrics. Participants will move a marker on a scale of 1-7 to answer each question.

Jian, J. Y., Bisantz, A. M., & Drury, C. G. (2000). Foundations for an empirically determined scale of trust in automated systems. *International journal of cognitive ergonomics*, *4*(1), 53-71

Instructions:

Next, you will fill out a series of questions for evaluating trust between people and automation. The questions include scales for you to rate the intensity of your feeling of trust, or your impression of the alert system.

Please move the marker to the point on the line that best describes your impression.

1. The alert system is deceptive. (1---2---3---4---5---6---7)
2. The alert system behaves in an underhanded manner. (1---2---3---4---5---6---7)
3. I am suspicious of the alert system's intent, actions, or outputs. (1---2---3---4---5---6---7)
4. I am wary of the alert system. (1---2---3---4---5---6---7)
5. The alert system's actions will have a harmful or injurious outcome. (1---2---3---4---5---6---7)
6. I am confident in the alert system. (1---2---3---4---5---6---7)
7. The alert system provides security. (1---2---3---4---5---6---7)
8. The alert system has integrity. (1---2---3---4---5---6---7)
9. The alert system is dependable. (1---2---3---4---5---6---7)
10. The alert system is reliable. (1---2---3---4---5---6---7)
11. I can trust the alert system. (1---2---3---4---5---6---7)
12. I am familiar with the alert system. (1---2---3---4---5---6---7)

APPENDIX F

POST-DRIVE HAZARD OBSERVANCE QUESTIONS

During instructions, participants will be told that they will be asked questions after each trial and will be given an example answer.

This prompt will be given to participants after each trial.

PROMPT: Based on the drive you just completed, please tell us about any important details, safety hazards, or problems you encountered while driving.

EXAMPLE: During the drive, I observed light traffic on the road. I noticed that as I was driving, I was alerted to the vehicle braking in front of me. I also noticed that there was a pedestrian crossing the street earlier in the drive before I took a right turn, that I had to avoid. The warning system also came on one time, but I already knew to stop to avoid an accident because I saw the brake lights. I didn’t notice anything else in particular.

APPENDIX G

RECRUITMENT SCRIPT

I am a student in the Human Systems Engineering program, part of the Ira A. Fulton Schools of engineering at Arizona State University.

I am conducting a research study to help determine how vehicle alerts can affect drivers' attention to hazards. This study aids our understanding of how to improve vehicle safety.

I am recruiting individuals to participate in a study. During the study, you would complete a series of trial drives in a driving simulator along with answering questions about the drives. You will follow driving directions in the simulator. Over the training and testing trials, the experiment will take approximately 30 minutes.

Your participation in this study is voluntary. You must be 18 years of age or older, have normal or corrected-to-normal vision (no color blindness), and be reasonably proficient in English language to participate. You must also have a valid US driver's license to participate If you have a history of motion sickness, you should not participate in this study.

If you are participating via a course, alternative course credit opportunities are available to you if you choose not to participate in this research study.

Your data will be used for research purposes only, such as academic publications and presentations. Your data will only be reported in aggregate or summarized form. Your responses are confidential. Your name and identifying information will not be collected as part of your survey responses. Thus, your name can never be linked to the data. Your responses are also voluntary. You are free to withdraw from the study at any time and choose not to answer questions. There are no anticipated risks to participating in this study.

If you have any questions concerning the research study, please email mmcalphi@asu.edu.

In addition, participants will be asked to complete a Motion Sickness Prescreen (link below):

https://forms.gle/tsYcLpCyPn6C4LqY7

APPENDIX H

IRB APPROVAL

ASU Knowledge Enterprise Development

APPROVAL: EXPEDITED REVIEW

Robert Gutzwiller
IAFSE-PS: Human Systems Engineering (HSE)
-
Robert.Gutzwiller@asu.edu

Dear Robert Gutzwiller:

On 10/20/2021 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Effects of Vehicle Warning Modality on Driving Hazards
Investigator:	Robert Gutzwiller
IRB ID:	STUDY00014699
Category of review:	
Funding:	Name: Arizona State University (ASU)
Grant Title:	
Grant ID:	
Documents Reviewed:	• All appendix content, Category: Other; • Informed Consent (CREDIT version), Category: Consent Form; • Informed Consent (PAID version), Category: Consent Form; • Protocol v3.0 - 11012021, Category: IRB Protocol; • Recruitment Form, Category: Recruitment Materials;

The IRB approved the protocol from 10/20/2021 to 10/19/2022 inclusive. Three weeks before 10/19/2022 you are to submit a completed Continuing Review application and required attachments to request continuing approval or closure.

If continuing review approval is not granted before the expiration date of 10/19/2022 approval of this protocol expires on that date. When consent is appropriate, you must use final, watermarked versions available under the "Documents" tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

REMINDER - All in-person interactions with human subjects require the completion of the ASU Daily Health Check by the ASU members prior to the interaction and the use of face coverings by researchers, research teams and research participants during the interaction. These requirements will minimize risk, protect health and support a safe research environment. These requirements apply both on- and off-campus.

The above change is effective as of July 29th 2021 until further notice and replaces all previously published guidance. Thank you for your continued commitment to ensuring a healthy and productive ASU community.

Sincerely,

IRB Administrator

cc:
Vipin Verma
Morgan McAlphin