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Dual-target hazard perception: Could identifying one hazard hinder a driver's capacity to find a second?

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ABSTRACT

Low-level cognitive processes like visual search are crucial for hazard detection. In dual-target searches, *subsequent search misses* (SSMs) are known to occur when the identification of one target impedes detection of another that is concurrently presented. Despite the high likelihood of concurrent hazards in busy driving environments, SSMs have not been empirically investigated in driving. In three studies, participants were asked to identify safety-related target(s) in simulated traffic scenes that contained zero, one, or two target(s) of low or high perceptual saliency. These targets were defined as objects or events that would have prevented safe travel in the direction indicated by an arrow preceding the traffic scene. Findings from the pilot study (n = 20) and Experiment 1 (n = 29) demonstrated that detecting one target hindered drivers' abilities to find a second from the same scene. In Experiment 2 (n = 30), explicit instructions regarding the level of risk were manipulated. It was found that search times were affected by the instructions, though SSMs persisted. Implications of SSMs in understanding the causes of some crashes are discussed, as well as future directions to improve ecological and criterion validity and to explore the roles of expertise and cognitive capabilities in multi-hazard detection.

1. Introduction

Efficiently scanning an environment to select and process visual information is an important skill for drivers (Crundall et al., 1998; Hosking et al., 2010; Huestegge et al., 2010; Ranney, 1994) and is known to be an influential factor in automobile collisions (Horswill et al., 2015, 2009; Horswill et al., 2010; McKenna and Crick, 1994). However, visual information processing failures can complicate many tasks on the road. For instance, distracted driving research has shown that visual processing is regularly compromised (Ranney et al., 2000; Sheridan, 2004) by secondary events like cell-phone conversations (McCarley et al., 2004) or text-messages (Drews et al., 2009; Strayer et al., 2006). It is generally agreed that these task-irrelevant distractions compete for attention in ways that disrupt visual processing on the road. However, is it possible for drivers' visual attention to be similarly compromised by focusing on multiple concurrent task-relevant stimuli? Consider the hypothetical case of a driver making a left turn at a four-way intersection at night. The driver waits for the highly visible perpendicular traffic to finish crossing straight through the intersection but fails to see a much less visible pedestrian crossing the street in the driver's path because the driver is focusing on the more salient vehicles passing through the intersection.

Subsequent Search Misses (SSMs) occur in visual search tasks when the correct detection of one target impedes detection of a second in the same scene (e.g., Adamo et al., 2013). Though this paradigm represents a well-known failure of visual attention, its implications to driver performance have not been explored. The research reported in this manuscript was developed to examine SSMs as a flaw that may be experienced by drivers.

Originally identified as a problem for radiologists, SSMs were thought to occur when observers became "satisfied" with their efforts after finding the first target. This idea is reflected by the paradigm's original title – "Satisfaction of Search" (SOS; Smith, 1967; Tuddenham, 1962). This phenomenon is still considered to be a prominent factor in diagnostic medical imaging (Ashman et al., 2000; Berbaum et al., 1998; Berbaum, 2012; Franken et al., 1994; Samuel et al., 1995; for a review, see Berbaum et al., 2010), though researchers have recently updated the phenomenon's title to reflect the error itself instead of a theory for the error (i.e., "Subsequent Search Miss"; Adamo et al., 2013; Cain et al., 2013). Although the "satisfaction" account for Subsequent Search Misses only became empirically supported recently (Adamo et al., 2015), researchers now acknowledge an array of cognitive mechanisms that facilitate one's failure to identify a second target (Adamo et al., 2013; Biggs et al., 2015; Biggs and Mitroff, 2014; Cain et al., 2013; Cain et al., 2011; Cain and Mitroff, 2013; Nakashima et al., 2013; Clark et al., 2014). For example, the resource depletion account for SSMs

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suggests that some of these errors are made because the first target's detection consumes cognitive resources that are necessary to locate and identify a second target in that scene (Adamo et al., 2013; Cain et al., 2013; Cain and Mitroff, 2013).

Though visual attention is critical to driving performance in many different ways (e.g., Ball et al., 1993; Chapman and Underwood, 1998a; Crundall et al., 2012; Konstantopoulos et al., 2010; Strayer et al., 2003), SSMs should be uniquely relevant to tasks that require scanning a cluttered environment to select and process visual information (i.e., perform visual searches; for a review of visual search, see: Eckstein, 2011). For instance, detecting safety-related information like hazards (Chapman and Underwood, 1998a; Chapman et al., 2002) and traffic signs (Ho et al., 2001; McPhee et al., 2004) can depend on a driver's ability to visually scan their environment. However, the dynamic nature of driving can complicate visual tasks by requiring drivers to track multiple objects over time (Lochner and Trick, 2014; Mackenzie and Harris, 2017), a factor that has been shown to increase SSM errors (Stothart et al., 2017).

Visual search of traffic scenes may also be guided by a wider variety of top-down features than other real-world visual searches. Leading theories of hazard perception for instance, describe drivers' knowledge and experiences as fueling mental models that guide visual attention in dangerous situations (Horswill and McKenna, 2004; Underwood, 2007). Research has found that, compared to novices, experienced drivers alter their visual scanning based on the complexity of road layouts (Crundall and Underwood, 1998; Underwood et al., 2002a; Underwood et al., 2002b), attend more to locations of potential risks (Garay-Vega et al., 2007), are more aware of hazardous situations on the road (Horswill and McKenna, 2004; Underwood et al., 2002aa, 2002b), and are also better at detecting traffic signs at expected locations (Borowsky et al., 2008). In other words, experienced drivers know where and when to look. This explains why many definitions of hazard perception (i.e., drivers' ability to perceive roadway hazards) go beyond detecting and responding to threats, by including a driver's ability to anticipate danger on the road (e.g., Horswill, 2016c; Lyon et al., 2011).

Hazard perception has typically been assessed by having drivers respond to video clips that contain hazardous situations (e.g., McKenna and Crick, 1994; Wetton et al., 2011). However, tests using static images have also been proposed as valid alternatives to examining driver hazard perception (e.g., Huestegge et al., 2010; Lyon et al., 2011; Scialfa et al., 2012a; Whelan et al., 2002). This suggests that it is feasible to investigate SSMs in driving with a method that closely mimics how SSMs have been traditionally examined in the laboratory with abstract stimuli (e.g., Fleck et al., 2010), in radiograph interpretation (e.g., Ashman et al., 2000; Berbaum et al., 2010), and baggage screening (e.g., Biggs et al., 2015).

Though it seems likely that SSMs could impact driving performance, traffic-related visual searches have unique task demands that may limit the effects of this phenomenon in the context of driving. In basic SSM experiments, participants are typically instructed to indiscriminately assess targets (i.e., "Ts") across the entire visual display (e.g., Fleck et al., 2010). Alternatively, drivers may restrict the criteria used to appraise objects as hazards based on characteristics like spatial location (e.g., pedestrians far away on the sidewalk may not necessarily become hazardous to a driver until they are stepping onto the street). The highly context-driven nature of a hazard's possible location might facilitate drivers' detection of them (Agrawal et al., 2017; Beck et al., 2014; Borowsky et al., 2008). Even though there is a multitude of research demonstrating that scene context guides spatial attention to facilitate target detection (Brockmole et al., 2006; Brockmole et al., 2008; Chun and Jiang, 1998; Chun, 2000; Mack and Eckstein, 2011; Torralba et al., 2006), the authors of the current manuscript are unaware of any research that specifically tests the effects of contextual cues on SSMs. Studying this may be important, as some of the environmental circumstances most likely to produce multiple hazards (e.g., higher traffic volume, larger number of lanes, or urban roadways) are also those that have been shown to be associated with more traffic accidents in general (Abdel-Aty and Radwan, 2000) and poorer hazard detection (Borowsky et al., 2012).

To begin investigating the role of SSMs in driving, the current research adopted a task procedure resembling other research measuring attention in the context of driving (Caird et al., 2005; 2018; Feng et al., 2015). The task used in this study involved drivers searching through 4 different types of simulated static driving scenes: (1) scenes containing one highly salient hazard, (2) scenes with an inconspicuous low-salience hazard, (3) scenes with both a high and a low-salience hazard, and (4) scenes without any hazards. A travel direction was provided before each scene as part of the driving context, and drivers were asked to assess the possibility of safely traveling through that scene in that direction.

Static images of simulated driving environments were used for this task so researchers could ensure that both hazards were presented to the drivers at the same time in the dual-target condition. This approach allowed the hazards' perceptual salience to be consistent throughout the trial, but also ensured that both hazards would be unambiguously hazardous when they were presented to drivers (Scialfa et al., 2012a). Another advantage of using static images is that it allowed researchers to present a large number of highly controlled scenes in a shorter amount of time. Admittedly, the video-based hazard perception tasks possess higher face validity and have been commonly used for research and driver licensure. However, there has also been a collection of evidence supporting the use of static images for examining driver perceptual and attentional processing of traffic scenes (e.g., Caird et al., 2005; Feng et al., 2015, 2018; Huestegge et al., 2010; Scialfa et al., 2013, 2012; Wetton et al., 2010). For example, Lyon et al. (2011) and Scialfa, Borkenhagen et al. (2012) developed static image-based hazard perception tests that successfully discriminated performance between experienced and novice drivers. Similarly, Marrington et al. (2008) reported a correlation between performance on a change detection task using static images and scores on a previously validated video-based hazard perception test. Using a similar method to the one in this manuscript, Feng et al. (2015) introduced driving context to an attention task with static scenes. In their study, drivers were shown directional cues before they were presented with road scenes from a driver's perspective as they approached an intersection. Participants had to quickly determine if it would have been safe to continue traveling in the direction indicated by the arrow. The findings revealed that drivers with lower accuracy on the image-based task also had poorer performance in a simulated driving task.

The support for the use of static images in other measures of driver attention and hazard perception suggest their use as a first step to studying SSMs in driver performance, particularly since most work with this paradigm has also used static images (e.g., Ashman et al., 2000; Fleck et al., 2010). However, this task may not accurately measure the full scope of hazard perception (e.g., anticipating threat based on the trajectory of a potential threat). Rather, its intent is to measure a more fundamental cognitive flaw that is likely to impede driving behaviors relying on visual attention, like detection of hazards.

It was hypothesized that participants' overall accuracy in this task would be higher for single-target scenes than dual-target scenes (H1), demonstrating a general SSM effect in hazard detection. However, a more conservative measure of the SSM effect involves comparing detection accuracy of low-salience targets in single-target conditions and in dual-target conditions where a high-salience target is also present (e.g., Biggs and Mitroff, 2014; Cain et al., 2011; Cain and Mitroff, 2013; Clark et al., 2014; Fleck et al., 2010). Therefore, the second hypothesis was that there would be a difference between single and dual-target trial accuracy for low-salience targets, once the high-salience target was found in dual trials (H2). In other words, the detection rate of low-salience targets would be higher in scenes when there is only one immediate threat and lower in scenes when the target is accompanied by another target of higher salience.

2. General methods

2.1. Materials

A dual-target hazard detection task was developed in order to examine the presence of SSMs that drivers may experience when searching for hazards. The stimuli consisted of simulated static traffic scenes (1024 × 768 pixels) from a driver's perspective created using SketchUp Pro 2016 (Version 16.0.1991.3 Mac 64-Bit, Trimble Navigation, Sunnyvale CA). Each scene subtended 48° x 28° of visual angle and contained a varying number of realistic items. Simply, each scene was designed to either be target-present, or target-absent, with targets specifically defined as items or events that would be hazardous to a driver's instructed path of travel. While target-absent scenes contained an array of task-irrelevant distractor items (i.e., irrelevant given they would not have obstructed safe passage), task-present scenes were those in which a hazard would have directly prevented safe passage in a vehicle from the participant's point of view. For example, a scene would be considered target-absent if it involved a driver approaching a four-way intersection that contained pedestrians walking on the sidewalks. However, the same scene would be considered target-present if those pedestrians were crossing the street in a way that occluded the driver's intended path of travel (see Table 1). Participants were specifically instructed to consider items as hazardous if their presence at the time of the scene would have made their passage unsafe. Thus, items were only considered hazardous in this task if they posed an immediate threat to drivers.

Similar to basic laboratory studies of SSMs, items had two levels of (bottom-up) perceptual features that provided the high or low salience distinction (Itti and Koch, 2000; Nothdurft, 2002; for reviews, see Itti and Koch, 2001 and Theeuwes, 1994). Criteria for saliency of items was determined primarily by manipulating color contrast between the items and their surroundings (D'Zmura, 1991; Nagy and Sanchez, 1990; Nothdurft, 1995; Treisman, 1985). In some cases, this also involved manipulating the similarity/dissimilarity between the targets' orientation in relation to their surroundings or manipulating the direction that items appeared to be traveling, or facing, in comparison to those that surround them (e.g., a series of cars face the same direction, except for one with a 45° rotation; Foster and Ward, 1991; Nakayama and Silverman, 1986; Nothdurft, 1992; Treisman and Gormican, 1988).

2.2. Procedure and design

The task used for this research was an amalgamation of the Drive Aware Task (DAT; Feng et al., 2015, 2018) and Fleck et al.'s (2010, experiment 3) SSM task. Fig. 1 shows an example trial of the current task. Each trial began with a cross appearing for 100 ms at the center of the screen. The cross was then followed by 1000 ms of an arrow, which pointed in one of three directions indicating the intended direction of travel (similar to the method used in Caird et al., 2005 and Feng et al., 2015, 2018). Following the directional arrow, a simulated traffic scene was presented before the participants were asked a series of follow-up questions. Participants were instructed that there would be either zero, one, or two targets in each scene. If participants noticed two targets, both should be reported and the reports should be in the order that the targets were noticed (similar to the method used in Fleck et al., 2010).

Each trial ended with 4 questions that participants answered using the computer keyboard: Participants were first asked whether or not it was safe to proceed in the direction indicated by the arrow which preceded the scene (Response 1). The second question asked how many objects or events directly impeded safe passage in the desired direction (Response 2). The third and fourth questions both asked which types of objects or events (i.e., target items) were noticed that may have obstructed passage in the desired direction (Responses 3 and 4). For these last two questions, participants were not only instructed to identify all of the objects or events that would have prevented safe passage during each scene but were also told that the order of objects or events which they report should be consistent with the order in which they noticed them. For example, if they first noticed a car and then a pedestrian, they would answer "vehicle" for Response 3 and "pedestrian" for Response 4. If there were no targets present, participants were still asked to respond to all four probes but simply indicate that no hazards were present in Responses 3 and 4. This was done so that participants would have an option to self-correct for false responses that may have been made hastily during the first two probes. This option to self-correct for motor errors has been shown to reduce false-alarms in low-prevalence visual search tasks by as much as 20% (Fleck and Mitroff, 2007; Kunar et al., 2017).

Participants were informed that each scene would contain one, two, or no target items. Of these scenes, 16% were dual-target trials, 16% single low-salience target trials, 20% single high-salience target trials, and 48% had no target (this trial distribution was chosen based on Experiment 3 from Fleck et al., 2010). Scenes of the dual-target trial

Table 1
Description of traffic scenes used for dual-target trials.

#	Direction	High-Salience Target	Low-Salience Target	Description
1	Right	Vehicle	Pedestrian	Car crash at intersection with pedestrian crossing on the right.
2	Right	Pedestrian	Other	Four-way intersection, with a pedestrian jumping on a skateboard in the center, and cat sitting in the intended path (on the right).
3	Right	Pedestrian	Pedestrian	A woman crosses the center of the intersection, walking her dog, and a child stands in the center of the street to the right.
4	Right	Vehicle	Other	Exiting a parking lot, a sports car occludes path and a dog is walking in the street to the right.
5	Right	Vehicle	Pedestrian	In a busy urban setting, an ambulance crosses the center as a pedestrian crosses the street on the right.
6	Right	Pedestrian	Traffic sign	A child skips across an intersection, and a "one way" street sign (pointing to the left) appears to the right.
7	Left	Vehicle	Pedestrian	An ambulance approaches directly facing the participants POV, and bicyclist crosses the street to the left.
8	Left	Vehicle	Traffic sign	Vehicles crashed in central area of the screen and a "do not enter" message preventing passage on road to the left.
9	Left	Other	Traffic light	Highway overpass with police directing traffic and red light at the intersection.
10	Left	Vehicle	Pedestrian	School bus stopped in a neighborhood and pedestrian crossing to the left
11	Left	Vehicle	Pedestrian	School bus letting students off and stop signals deployed, family crossing the street on left.
12	Straight	Vehicle	Pedestrian	An ambulance approaches from the right, into the center and a bicyclist crosses the street behind it.
13	Straight	Vehicle	Traffic light	A car is crashed in the center of the road, and a red light appears above.
14	Straight	Vehicle	Traffic light	A busy four-way intersection with a car that crashed into a lamp poll in center of the road. Above the crashed car is a red light.
15	Straight	Pedestrian	Other	A neighborhood street in the rain. A pedestrian has fallen in the road, and a tree has fallen in the street a bit further down the street.
16	Straight	Pedestrian	Pedestrian	Four-way intersection, with bicyclist passing in front of the driver's point of view and a running crossing the street to the left.

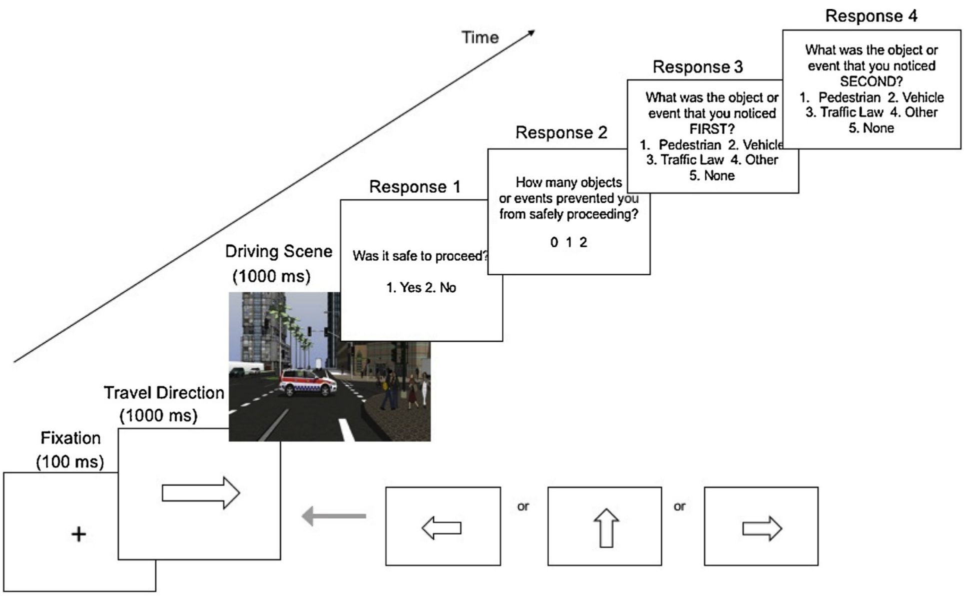

Fig. 1. An example trial of the dual-target hazard perception task in Experiment 1. In each trial, an arrow indicated the desired travel direction to provide context in the hazard perception in the following scene. Participants were given thorough instructions regarding how to classify potentially ambiguous hazards. For example, routine items that dictate the flow of traffic (e.g., traffic lights) should be considered a "Traffic Law.".

always contained one low and one high-salience target, but participants were not warned about any salience manipulation. In order to provide a more conservative measure of a high-salience item's impact on subsequent target detection, single low-salience target and dual-target scenes were identical aside from the addition of a high-salience target in dual-target trials.

Each session began with an experimenter reading instructions aloud to the participants before they were assisted with 12 practice examples with trial distribution similar to the actual experiment. They were told that accuracy feedback would be given after each scene in the practice block but end once the actual experiment began. After the practice trials, the experiment contained 4 blocks of 25 randomized trials, and participants were given an option to take a break after each block or press a button on the keyboard to continue. The proportion of trials used in each block was consistent throughout all four blocks of the experiment (e.g., the same number of dual trials in each block). In addition, a single low-salience target trial was always presented in a different block than its dual-target replica in order to resist the facilitation of accuracy from searching in a familiar scene (Brockmole et al., 2006). The experiment was built using E-Prime (Version 2.0, Psychology Software Tools, Pittsburgh, PA) on a PC with a 27-inch monitor with a resolution of 1920 × 1080 pixels (Dell, 60 Hz).

2.3. Saliency validation

To validate the saliency of the targets used in the study, we relied on an algorithm that generates "saliency maps" of images (Walther and Koch, 2006). These saliency maps operate by exposing areas in two-dimensional images where attention is most likely to be deployed next, based on the concept of rankings that are awarded to spaces with the most conspicuous perceptual attributes (Itti and Koch, 2000; Koch and Ullman, 1985).

First, the five areas of highest perceptual salience were computed for the dual-target scenes (See Fig. 2). Researchers then calculated a rate for the presence of each hazard's appearance in those five areas. Thus, if a target appeared in two of the five most salient spaces on the image, that target's rate for appearance would be 0.4. Rates were calculated for each of the two hazards in the 16 dual-hazard trials, and then tested against each other using a paired-samples t-test. This revealed a robust difference between the frequency of the two targets appearing within the five most salient areas of the scenes, $t(17) = 4.27$, $p = .001$, Cohen's $d = 1.51$, with high-salience ($M = 0.17$, $SE = 0.02$) targets appearing far more often than the low-salience targets ($M = 0.04$, $SE = 0.02$).

3. A pilot study

As this study was the first to investigate SSMs in the context of driving, we started with a pilot study to assess the suitability of settings of the task, including the task instruction, the exposure time of the driving scenes, the response method, as well as the analyses of SSMs.

3.1. Methods

20 undergraduate students (eight men, 12 women) from a large research university participated in piloting an experiment for course credits. All participants reported normal, or corrected-to-normal, vision and were licensed drivers. The study was approved by the University's Institutional Review Board, and informed consent was collected for all participants. In this pilot of the experiment, each scene was presented to participants for only 1000 ms. This was based on the stimulus presentation time from the original DAT (2018, Feng et al., 2015).

3.2. Results

3.2.1. Accuracies of Responses 1 & 2

Response 1 (i.e., "Was it safe to proceed?") accuracy (i.e., percentage of correct responses) was generally high across all trials, though Response 2 (i.e., "How many object or events prevented safe passage?") accuracy was a bit lower (see Table 2). A comparison of low-salience target accuracies for dual-target and single-target trials (SSMs are typically a comparison of accuracy in these two types of trials) revealed significant differences between these trials for both Response 1, $t(19) = 7.57$, $p < .001$, Cohen's $d = 2.16$, and Response 2, $t(19) = 12.62$, $p < .001$, Cohen's $d = 4.17$. When a high-salience target occurred in addition to a low-salience one (i.e., in the dual-target trials), participants were much more likely to respond correctly on whether to proceed compared to trials that just contained a single low-salience hazard. However, data from Response 2 supported the hypothesis that participants were less apt in their ability to identify a second target after already finding one in a scene (H1). In order to further determine the nature of these errors and test H2 (i.e., low-salience target accuracy being particularly vulnerable to the presence of a high-salience target), we proceeded to the analysis concerning how the physical salience of targets impacted the likelihood of their identification.

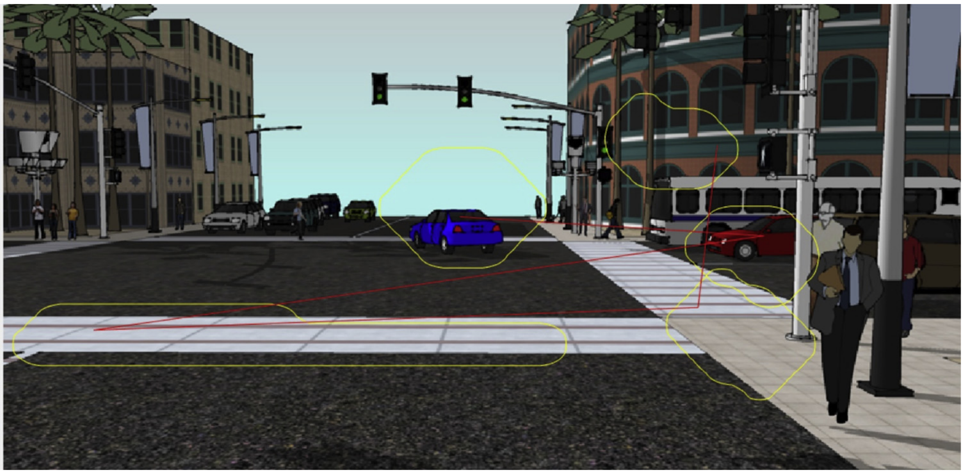

Fig. 2. Analysis of salience of one of the scenes from the dual-target hazard perception task using Walther and Koch (2006) algorithm. The output of this algorithm provides the most visually salient areas in an image. For validation of the stimuli in these experiments, researchers sought the five most visually salient locations in each image. In this scene, the high-salience target (blue sedan) appears as the most salient, while the low-salience target (pedestrian) is to the left of the blue sedan and not among the top five salient areas (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

3.2.2. Subsequent search misses (SSMs)

A preliminary summary of data from the pilot study have been written about previously (Sall and Feng, 2016), albeit with slightly different methods for the selection of trials for analysis. For all of the data in the current manuscript, dual-target trials were only included when the high-salience target was correctly identified first. This procedure for data cleaning is thought to provide the most conservative measure of SSMs (e.g., Adamo et al., 2013; Adamo et al., 2015), given that it focuses specifically on testing the hypothesis of high-salience targets interfering with detection of low-salience targets in dual-target trials. Furthermore, the subjectivity of the current task prompted the authors of this manuscript to exclude trials with false-positives. These criteria left researchers with 75% of dual-target trials for the analysis.

The primary measure for Subsequent Search Misses (SSMs) was a comparison of low-salience target detection accuracy between single and dual-target trials (Fleck et al., 2010). Accuracy values for single-target trials came by dividing the total number of correct answers in response 3 (i.e., “Which target did you FIRST notice in the scene?”), by the total number of usable scenes for each trial type. Furthermore, single low-salience trials were only included if participants correctly identified the target in the scene, and subsequently reported no other targets in the scene, resulting in 81% of them being included in this part of the analysis. Though most indices of the SSM effect involve this specific comparison of low-salience hazards, the phenomenon has also been documented without this perceptual salience manipulation (Cheng and Rich, 2018; Stothart et al., 2017). Therefore, the authors tested the hypotheses with separate analyses for low-salience and high-salience targets.

In order to test the first hypothesis involving a general comparison of dual and single hazard scenes, a 2 × 2 repeated-measures ANOVA was conducted using trial (single or dual) and target type (high- or low-salience) as within-subject factors. A main effect was seen for target type, $F(1,19) = 192.67$, $p < .001$, $\eta_p^2 = .91$, in that participants’ accuracy (i.e., percentage of correct detection) was generally higher for high-salience targets ($M = 97.7\%$, $SE = 1.1\%$) than low-salience targets ($M = 50.2\%$, $SE = 3.9\%$), further supporting the saliency manipulation.

A main effect was also seen for trial type, $F(1,19) = 120.82$, $p < .001$, $\eta_p^2 = .86$, with lower overall accuracy in dual-target searches ($M = 63.7\%$, $SE = 2.7\%$) when compared to single-target trials ($M = 84.1\%$, $SE = 2.2\%$), providing support for the first hypothesis (H1) that hazard detection accuracy is better in single-target trials than dual-target trials. There was a significant interaction between target (high vs low-salience) and trial types (single vs. dual-target), $F(1,19) = 94.32$, $p < .001$, $\eta_p^2 = .83$.

A planned pairwise comparison was consistent with the second hypothesis (H2), that participants’ accuracy for identifying low-salience targets would be higher when the targets were presented on their own (single hazard condition: $M = 70.4\%$, $SE = 4.1\%$), compared to when presented simultaneously with a high-salience target (dual-hazard conditions: $M = 30.1\%$, $SE = 4.5\%$), $t(19) = 11.41$, $p < .001$, Cohen’s d = 2.09 (see: Fig. 3a).

3.3. Discussion

The data collection and analysis of this pilot study demonstrated suitability of the general method and the settings for the task. These data reveal a novel trend regarding the ability of drivers to attend to

Table 2
Percentage of Correct Response for Response 1 (“Was it safe to proceed?”) and Response 2 (“How many objects or events prevented safe passage?”) across Experiments and Trial Types.

	Trial Type	Pilot Study		Experiment 1		Experiment 2 - High Risk		Experiment 2 - Low Risk	
		M	SD	M	SD	M	SD	M	SD
Response 1	Dual	96.9	5.6	99.4	1.9	95.7	13.5	96.4	8.2
	Single (low-salience)	71.9	15.4	88.6	9.6	82.8	16.2	80.8	20.3
	Single (high-salience)	98.0	3.8	96.4	4.6	95.5	9.9	97.1	6.0
	No target	90.1	6.9	93.4	5.4	92.0	8.2	92.1	9.8
Response 2	Dual	33.1	17.8	75.4	12.6	60.3	25.9	54.0	29.1
	Single (low-salience)	68.1	16.6	85.6	10.0	78.0	19.1	79.5	17.8
	Single (high-salience)	87.8	10.1	87.6	10.7	84.8	15.0	86.4	13.4
	No target	89.6	7.0	93.5	5.2	90.5	10.8	89.1	17.4

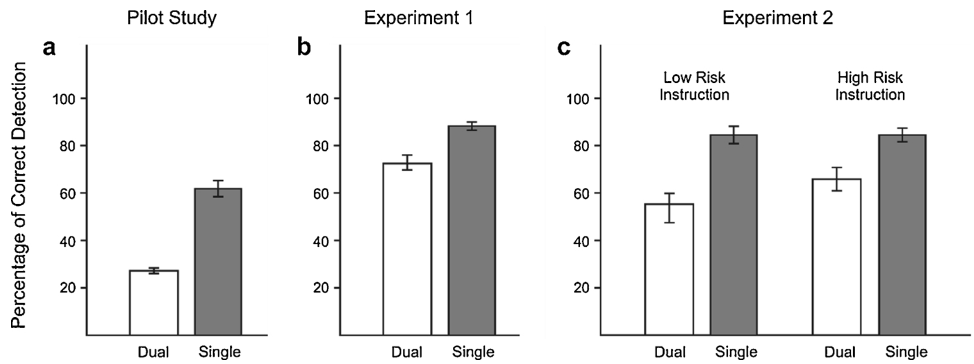

Fig. 3. Results of low-salience target accuracies for the pilot study (a), Experiment 1 (b), and Experiment 2 (c). Dual-target accuracies are shown by the white bars on the left, and gray bars represent single, low-salience target accuracy. Error bars represent +/- one standard error of the mean.

multiple concurrent hazards. That is, after finding one highly salient hazard on the road, drivers may be more likely to miss the second hazard. One limitation discovered in this pilot was the relatively brief stimulus presentation time. The 1000 ms of stimulus presentation offered in this experiment was intended to mirror many real-world occurrences of the time window available for drivers needing to perform hazard detection, where drivers might be forced to quickly respond to events on the road. It could be argued, however, that this exposure time was too brief for the complex road scenes to allow deliberate visual searches. Furthermore, most of the participants were still able to respond to the first question (i.e., “Was it safe to proceed?”) with high accuracy, meaning that some real-world behavioral responses (i.e., braking) might allow for longer search times. Therefore, Experiment 1 was conducted with extended search times.

4. Experiment 1

The first experiment followed the same procedure as the pilot study, but it offered drivers a longer window of time to search the scenes. While participants are known to succumb to SSMs in basic visual search tasks that allow up to 30 s of search times (Fleck et al., 2010), it was uncertain how the search time extension could influence target detection in the current experiment. With the extension of the search times in this experiment, participants were allowed to terminate their search if they felt that they had accurately assessed the safety of the scene before the maximum allowable time had elapsed. This is important for researchers, because search times offer a valuable metric for Subsequent Search Miss errors (Adamo et al., 2015; Berbaum et al., 1991; Cain et al., 2013). For example, evidence for the original “satisfaction” account of these errors comes from measuring the amount of time participants continue to search after finding one target and terminating the trial (e.g., Adamo et al., 2015; Cain et al., 2013). While the current task did not allow for this specific type of analysis, it was of some interest to compare search times for dual-target trials where participants correctly identify both targets, from trials where only the high-salient target was identified. If the total amount of time searching did not differ between those two cases of dual-target trials, then it is unlikely that the satisfaction hypothesis was highly prevalent in this experiment. If the search times did differ though, this would provide some evidence for “satisfaction” in the search for hazards on the road. Therefore, in addition to hypotheses 1 and 2 from the first experiment, the authors were interested in exploring the extent with which a “satisfaction” effect (Adamo et al., 2015; Cain et al., 2013) could impact hazard detection performance in the task.

4.1. Methods

29 undergraduates (11 men, 18 women; age: M = 19.4 years, SD = 1.5), with normal or corrected-to-normal vision and valid drivers' licenses, were recruited for Experiment 2. The task and design were both identical to the pilot study with two exceptions. First, participants were offered an additional 4000 ms to search for hazards in each scene. This brought the allowable time participants could search for hazards from 1000 ms in the pilot study to 5000 ms in Experiment 1. Second, participants were told that they could terminate their search before the 5000 ms elapsed, with explicit instructions to value speed and accuracy equally.

4.2. Results

4.2.1. Accuracies of Responses 1 & 2

Participants' performance for both trial types were identical to those in the pilot study (Table 2). For Response 1 (i.e., “Yes” or “No” to “Was it safe to proceed?”), accuracy was significantly lower in the single-target trials (M = 88.6%, SE = 17.8%) than the dual-target trials (M = 99.4%, SE = 0.4%), $t(28) = 5.72$, $p < .001$, Cohen's d = 1.55. For accuracy on Response 2 (i.e., 0, 1, or 2 target(s)), participants reported higher accuracy for the single-target scenes (M = 85.6%, SE = 10.0%), than dual-target scenes (M = 75.4%, SE = 12.6%), $t(28) = 5.01$, $p < .001$, Cohen's d = .89, providing some support for H1 that the overall accuracy would be higher for single-target trials.

4.2.2. Subsequent search misses

The selection criteria of these data and subsequent analyses were similar to those from the pilot study. This resulted in the inclusion of 71% of the dual-target and 100% of the single low-salience trials. A 2 × 2 repeated measures ANOVA revealed a significant main effect for trial type, $F(1,28) = 89.87$, $p < .001, \eta_p^2 = .76$, with the accuracy on single-target trials (M = 92.3%, SE = 1.3%) being higher than dual-target trials (M = 76.2%, SE = 2.0%; See Fig. 3b), further supporting H1 (i.e., hazards are easier to identify in isolation than in tandem with another hazard). A main effect was also seen for target type, $F(1,28) = 10.04$, $p = .004$, $\eta_p^2 = .26$, with high-salience targets (M = 88.0%, SE = 1.6%) being found more frequently than low-salience targets (M = 80.6%, SE = 2.1%), though there did not appear to be a significant interaction between trial and salience, $F(1,28) = .32$, p = .574, $\eta_p^2 = .01$.

Similar to the pilot study, a planned pairwise comparison of low-salience targets was carried out in order to look for the effects that high-salience targets had on low-salience target accuracy (H2). Accuracy for low-salience targets was significantly higher in single-target trials (M = 88.2%, SE = 1.7%) than when they were accompanied by another in the dual-target trials (M = 72.9%, SE = 3.0%), $t(28) = 6.13$, $p < .001$, Cohen's d = 1.17. This is consistent with the findings in the pilot study and further supports H2.

4.2.3. Search time

Search time was calculated from the onset of the stimulus traffic scene to the participant's response, or the trial's natural end. A repeated-measures ANOVA was conducted comparing the search times for all trials (M = 3502 ms, SE = 225 ms). Non-significant differences were found for the time spent searching across the four different trial types, $F(1.75, 48.97) = 1.09$, $p = .337$, $\eta_p^2 = .04$ (adjusted for a violation of sphericity as recommended by: Greenhouse and Geisser, 1959; Huynh and Feldt, 1976), suggesting no evidence for a speed accuracy trade-off in the hazard detection task.

4.3. Discussion

The findings from this experiment suggest that merely slowing down to prevent a collision might not be sufficient to adequately scan the environment when multiple hazards are present. Overall hazard detection accuracy in single-target trials was still higher than dual-target condition, especially for low-salience targets, even when participants were allowed to search for a longer time. Thus, while the first experiment provided some evidence that drivers who rapidly approach multiple hazards may succumb to Subsequent Search Misses (SSM), this follow-up offers converging evidence that drivers may continue to face these problems even when given longer times to scan their environments (e.g., when using the brakes to slow down).

5. Experiment 2

Experiment 1 further confirmed the presence of an SSM-like effect while searching for targets in simulated traffic scenes. However, performance is known to be highly susceptible to task-related features of basic SSM experiments like instructions (Cain et al., 2011) or target prevalence (Cheng and Rich, 2018; Fleck et al., 2010). Similarly, knowledge of patient's clinical history has been shown to improve visual searches for radiologists (Berbaum et al., 1993; Berbaum et al., 1994; Elmore et al., 1997), with some changes in behavior observed from the mere suggestion that an upcoming radiograph might be of either high or low difficulty (Brunyé et al., 2016). These behavioral changes from a single generic warning may be highly relevant to the task described within this manuscript, given that changes in perceived danger have been known to affect visual search strategy during other hazard perception tasks (Chapman and Underwood, 1998a, 1998b). Furthermore, basic theories of adaptive attentional shifts (Aston-Jones and Cohen, 2005; Zacks et al., 2007) seem to suggest that generic warning systems would be generally useful tools for eliciting behavioral changes in drivers (Cummings et al., 2007; Thoma et al., 2009).

To test the impact of generic contextual warnings in the current paradigm, the second experiment involved a variation of the previous experiment that included unique sets of instructions indicating the risk of multiple hazards that were presented before each block. The warning conditions were primarily inspired by variable message signs (VMS) – dynamic traffic signs that are able to present information to drivers in real-time (e.g., Fig. 4). Variable message signs are generally successful in their abilities to inform drivers of traffic conditions and are viewed favorably by most drivers (Chatterjee and Mcdonald, 2004). Furthermore, at least some evidence supports the efficacy of these messages' abilities to elicit behavioral compliance from drivers (Erke et al., 2007). Importantly though, they are well-suited to display the kind of generic warnings that might prompt drivers to be aware of an array of hazardous situations, including the risk of multiple hazards on the road.

While the two hypotheses outlined in the pilot study and the first experiment were both tested in this second experiment, the use of risk warnings provided an additional set of hypotheses to be tested. First, it was hypothesized that instructions indicating a high risk of multiple hazards would result in longer search times (H3), as well as higher accuracy for low-salience targets in dual-target trials (H4).

5.1. Methods

30 undergraduates (11 men, 19 women) aged 18 to 23 years (M = 19.2 years, SD = 1.2) were recruited for this experiment. However, two participants' data were excluded from the final analysis after reports of not having normal or corrected-to-normal vision, or not having a driver's license. The procedure and stimuli here were identical to those in Experiment 2, with one exception: a single word was presented at the beginning of each block indicating whether or not the upcoming scenes had a high or low risk of multiple hazards being present in them. However, neither the scenes contained in each block, nor the order of the blocks themselves, changed in this experiment (though the order of scenes within each block was randomized within the respective blocks). Rather, the risk manipulation was balanced between participants so that each block had an equal number of both risk warning sets (i.e., *high, low, low, high* vs. *low, high, high, low*) assigned to it.

5.2. Results

Responses to the first two questions (i.e. "Was it safe to proceed?" and "How many objects or events prevented you from safely proceeding?") were analyzed to first gain some insights into the presence of faulty dual-target visual search across the different risk manipulations (i.e., high vs low). A repeated-measures ANOVA was conducted for accuracy using the within-subject variables of risk (high vs low), and trial type (dual vs single). Overall, risk did not have an effect on Responses 1, $F(1,28) = .78$, $p = .385$, $\eta_p^2 = .03$, though a significant difference was observed between the dual and single low-salience target trials, $F(1,28) = 75.57$, $p < .001$, $\eta_p^2 = .73$. Similar to our earlier findings, participants were more able to detect at least one target in the dual-target trials (M = 96.1%, SE = 1.5%) than in the single-target conditions (M = 81.3%, SE = 2.5%). This direction did not appear to be significantly influenced by risk, as indicated by a non-significant interaction between risk and trial, $F(1,28) = 2.34$, $p = .137$, $\eta_p^2 = .08$. For accuracy on Response 2 (i.e., "How many objects or events prevented safe passage?"), a repeated-measure ANOVA revealed a non-significant main effect for risk, $F(1,28) = 1.98$, $p = .170$, $\eta_p^2 = .07$. However, there was a significant main effect for trial, $F(1,28) = 45.82$, $p < .001$, $\eta_p^2 = .62$, that was accompanied by a non-significant risk by trial interaction, $F(1,28) = 1.49$, $p = .233$, $\eta_p^2 = .05$, despite the reasonably large magnitude of the accuracy difference between dual-target trial responses from the low (M = 51.7%, SE = 5.4%) and high risk (M = 61.2%, SE = 4.6%) trials. While these data provide support for H1 (i.e., overall higher accuracy in single target trials), testing the rest of the hypotheses would once again involve comparisons of the two identification responses (i.e., Responses 3 & 4).

5.2.1. Subsequent search misses

Two separate analyses were conducted for high and low-salience trials across both risk instructions, similar to Cain and Mitroff (2013). Two 2 × 2 repeated-measures ANOVAs (one for high-salience targets, another for low-salience targets) were used to compare mean accuracies across trial types (single and dual), and levels of risk (high and low) for the last two identification questions (using the 79% of dual-target and 81% of single, low-salience trials that met inclusion criteria outlined earlier this paper).

5.2.1.1. High-salience target detection. Risk did not have an overall main effect, $F(1,26) = .60$, $p = .448$, $\eta_p^2 = .02$ for high-salience hazard accuracy. Furthermore, accuracy for the high-salience hazards did not appear to differ significantly between the dual-target and single-target trials, $F(1,26) = 2.98$, $p = .096$, $\eta_p^2 = .10$, nor was a significant risk by trial interaction found for these data, $F(1,26) = .80$, $p = .380$, $\eta_p^2 = .03$.

Fig. 4. An example of Variable Message Signs (VMS), taken from Lennington (2016), October 14).

5.2.1.2. Low-salience target detection. Overall, risk did not have an impact on low-salience target accuracy, $F(1,26) = 2.31$, $p < .140$, $\eta_p^2 = .08$, though there was an main effect for trial type, with higher accuracy in single-target (M = 59.1%, SE = 5.0%) than dual-target (M = 84.7%, SE = 2.8%) trials, $F(1,26) = 45.95$, $p < .001$, $\eta_p^2 = .64$, demonstrating further support for H2 (a difference specifically for low-salience hazards).

While the risk by trial interaction did manage to reach significance, $F(1,26) = 4.31$, $p = .048$, $\eta_p^2 = .14$, the weak effect size indicates that little variance in these data could be attributed to the risk manipulation from the experiment. Furthermore, pairwise comparison suggested that even though the difference in high and low-risk instructions provided marginal significance for dual-target trials, $t(26) = 2.05$, $p = .050$, the comparison of single-target trial accuracy across risk instructions was far from significant, $t(26) = .07$, $p = .946$. These data suggest that the risk instruction may have some impact on SSM rates, though support for this hypothesis should be considered moderate.

5.2.2. Search time

To gain a better understanding for the way that risk level influenced hazard detection performance, the total amount of time spent searching was entered into a 2 × 4 repeated-measures ANOVA with risk (High and Low) and trial type (Dual, Single Low-Salience, Single High-Salience, and No-Target) as within-subject factors. A main effect for risk, $F(1,27) = 6.60$, $p = .016$, $\eta_p^2 = .20$, demonstrated that participants searched for a longer time before terminating their search when under a high-risk warning (M = 3397 ms, SE = 220 ms), than when under a low-risk warning (M = 3232 ms, SE = 252 ms). Unlike what was seen across accuracy, participants' search times did not appear to be particularly influenced by trial type, $F(1.31, 35.37) = 1.69$, $p = .203$, $\eta_p^2 = .03$ (adjusted for a violation of sphericity as recommended by: Greenhouse and Geisser, 1959; Huynh and Feldt, 1976). Furthermore, the lack of significant interaction between these two variables, $F(3,81) = .64$, $p = .591$, $\eta_p^2 = .02$, suggested that the risk influence was not specific to any particular trial type. Therefore, our results suggest that participants allocated more time to searching trials when instructions indicated a high risk of multiple hazards being present.

5.3. Discussion

The results of Experiment 2 seemed to provide, at least some, evidence that participants were encouraged to adapt their search performance when faced with instructions about the likelihood of multiple hazards being present, despite the extremely low frequency of the dual-target trials being present. While there was unclear evidence for the hypothesis that these risk warnings would affect accuracy (H4), the longer search times for high-risk trials seemed to offer reasonable support for H3. Thus, the risk instruction manipulation from this experiment suggests drivers experienced a general mechanistic change that involve alterations of search time and accuracy, related to both effort and processing efficiency.

6. General discussion

The experiments described in this manuscript provide empirical support for a novel application of faulty attention that may be experienced by drivers. Specifically, a general Subsequent Search Miss (SSM) effect (e.g., Cain et al., 2013) was observed across three studies using simulated traffic scenes, indicating that drivers experienced a decrement in hazard detection accuracy when multiple hazards were presented simultaneously. A broad implication of this research is that drivers' processing of task-relevant traffic stimuli may actually impede their ability to concurrently attend to similar task-relevant information. These data may be useful for industry practitioners whose work involves traffic accident diagnostics. However, it is important for researchers to continue studying this phenomenon in different driving contexts in order to reduce these lapses of attention during hazard detection.

Though the static images from this study present an obvious limitation, the use of these stimuli had several justifications. First, static images have been used to observe a number of other important findings related to driver performance, including hazard perception (De Craen et al., 2008; Ho et al., 2001; Huestegge et al., 2010; Scialfa et al., 2013; Whelan et al., 2002). Additionally, the static traffic in this study allowed for more traditional SSM analyses developed with static images (e.g., Adamo et al., 2013; Fleck et al., 2010). Another benefit of this method was that the static images ensured that drivers would be presented with moments when both hazards were unambiguously relevant to their safe passage. This ability to measure responses to specific pieces of task-relevant information has been regarded as a benefit of static images in hazard perception tasks, given that there is no uncertainty regarding a potential hazard's onset (Scialfa et al., 2012aa, 2012b).

Despite the strengths offered by this study's approach, a prominent limitation is the absence of dynamic stimuli. This limitation is reflected in work on hazard perception by Wetton et al. (2010)), who described three components of hazard perception: hazard detection (i.e., driver registers the hazardous object/event), trajectory judgement (i.e., driver judges whether the trajectories of the perceived object/event and his/her own car pose a conflict), and hazard classification (i.e., driver determines whether a response is needed). The examination of SSMs in this study could be considered to have primarily involved hazard detection, with some involvement of hazard classification, but limited trajectory judgement. Replications with dynamic hazard perception tests will be necessary to establish ecological and criterion validity (e.g., Wetton et al., 2011), given that they can incorporate those missing elements from Wetton et al. (2010)) framework. One potential challenge with future work on developing a dynamic version of the task is generating enough stimuli to have appropriate statistical power. Dynamic versions will likely require adopting methods used to study this phenomenon in radiology (e.g., ROC curve analysis; see Berbaum, 2012), as it is common for these studies to include fewer observations per subject.

Support for a hypothesis regarding successful replication of these findings in dynamic scenes can be extracted from some of the theoretical studies of Subsequent Search Misses. First, SSMs are uniquely tied to the *attentional blink* (AB) phenomenon that occurs over a temporal stream. When stimuli in an AB task are individually presented in a rapid-serial-visual-presentation (RSVP), it's found that correctly identifying one target impedes detection of another that is presented 200–500 ms after the first (Broadbent and Broadbent, 1987; Raymond et al., 1992). When Adamo et al. (2013) investigated eye-movements that searchers made during a basic SSM task (i.e., searching for Ts amongst Ls), it was found that accuracy for second targets in dual trials was lower when the time between identifying the first target and fixating on the second target fell within a similar time 200–500 ms window (i.e., "lag-2″; Adamo et al., 2013). In other words, the processing demands of the first target inhibited processing further task-relevant information. This "*pseudo*-attentional blink" finding suggests that the information processing limitation observed using this study's static imagery may also affect visual attention performance over time (e.g., with moving targets). In line with this hypothesis, other research has shown that the SSM effect not only persists when observers scan scenes that contained moving Ts and Ls, it can become even more robust than in static scenes (Stothart et al., 2017). Taken together, these studies seem to suggest that the hindrances of hazard detection demonstrated in this experiment will carry over when increasing the ecological validity with dynamic simulations (i.e., dynamic traffic environments).

Future research with this paradigm would also benefit from exploring this specific dual-target hazard search task's ability to predict real-world driving performance measures. Establishing this relationship is important for laboratory tasks, as training with ecologically valid instruments are likely to be more efficient at reducing on-road crash risks (2016b, Horswill, 2016a). Existing data from initial research with the Drive Aware Task (DAT; Feng et al., 2015, 2018), from which the dual-target hazard perception task in this study was developed, may shed some light on the task's validity. When comparing responses on the original version of the DAT with driving simulator performance, Driver Aware Task accuracy was significantly associated with errors made during the simulated drive (Feng et al., 2015). It is important to note that the task used to measure SSMs in this manuscript was highly similar to the original DAT, with only minor changes made to the stimuli to elicit and measure the SSM effect. However, rather than trials containing no hazards, a single hazard, or dual-hazard trials, the original DAT only used single-hazard and target-absent trials (Feng et al., 2015). Despite the evidence from this driving simulator study to support the DAT's validity, it is still in need of validation using real-world driving performance.

In addition to validating the task used here to measure SSMs (i.e., the DAT), more work is needed to investigate the nature of hazards in this dual-target paradigm. For example, it is possible that one hazard may have unique anticipatory cues that either facilitate or further inhibit detection of a second. Given the importance of anticipation in hazard perception skill acquisition, studying the relationship between simultaneously presented hazards may play an important role in SSM-reduction training (Horswill, 2016a). In similar work, it was found that similarities between simultaneously presented targets can impact SSM rates. Biggs et al. (2015) conducted simulated baggage screening experiments using static images to show that when two targets in the same trial shared either perceptual (e.g., same color) or conceptual features (e.g., both weapons), the SSM effect was significantly reduced.

Though SSM tasks have primarily involved manipulations to the bottom-up properties (physical characteristics like color and shape), human factors work on conspicuity has shown that hazards are also processed according to their top-down (e.g., Theeuwes, 1994) attentional salience (Hole and Tyrrell, 1995; Hole et al., 1996). Future work on SSMs in driving may consider manipulating top-down salience without changes to bottom-up features. In a collision described by Chabris and Simons (2010), NFL superstar Ben Roethlisberger was hit on his motorcycle as he was passing through an intersection. The driver who hit Roethlisberger was making a left turn through the same intersection but failed to notice the motorcycle as they monitored the rest of the intersection. One interpretation of this incident is that differences in top-down saliency between the traffic light (higher top-down salience) and motorcycle (lower top-down salience) contributed to an SSM effect from Roethlisberger's assailant. It is also possible that the SSM effect in this scenario was facilitated by the perceptual/conceptual set biases demonstrated by Biggs et al. (2015) luggage screening simulation. Investigating conceptual and perceptual set biases between simultaneously presented hazards, along with the importance of top-down salience differences between targets, may offer unique advantages for researchers studying inexperienced drivers. If experience-related differences in hazard perception occur from underdeveloped mental models of the road (Endsley, 1995; Horswill and McKenna, 2004; Underwood, 2007), it is possible that those incomplete knowledge representations might exacerbate conceptual set biases in SSMs. In addition to testing conceptual and perceptual set biases for SSMs during hazard perception, future studies would benefit from comparing novice and experienced drivers' rates of SSMs in driving tasks.

One possible limitation of this study is the use of traffic signs in addition to standard hazards that drivers are responsible for reporting. While these items may not necessarily be considered hazards on their own, they signal situations that could be hazardous to the drivers (e.g., running a red light). However, the instructions used in this study specified that drivers should "identify all objects or events that would have prevented safe passage," with a specific mention to include traffic signs. Participants were also given enough experience with the task during the initial practice trials that traffic signs should have been included in their search schemas. In future examinations of SSMs in driving, particularly those focusing on conceptual set biases for novice and experienced drivers, researchers may consider controlling for the relative difference in perceived threat between two concurrently presented hazards.

Another interesting future direction could be determining if age-related cognitive and perceptual changes have differential impacts on SSMs in hazard perception. Given that drivers begin to experience diminished hazards perception between the ages of 65 and 75 (Horswill et al., 2009, 2010; Scialfa et al., 2012aa; Sekuler, Bennett, and Mamelak, 2000), it may be beneficial to investigate this group's ability to detect multiple hazards simultaneously. Though little is known about age-group differences in SSMs, data have shown Drive Aware Task accuracy to be sensitive to age-group differences for the decision criteria used by drivers to detect hazards (Feng et al., 2018). In this study, older drivers showed a bias toward reporting hazards in cluttered scenes with heavy traffic loads over the less cluttered scenes, despite the actual prevalence of hazards being the same for both traffic-load condition (Feng et al., 2018). While it is difficult to determine how this finding will affect SSMs in older drivers, one hypothesis is that older drivers are more prone to "satisfaction" induced (Adamo et al., 2015) SSM-related lapses resulting from their selectivity for resource expenditure (Hess, 2014). Another possibility is that age-related decrements in selective spatial attention will worsen SSMs for hazards beyond certain eccentricities (Ball et al., 1988; Feng et al., 2017; Sekuler et al., 2000).

An important finding from the current study was that the SSMs in hazard detection persisted despite participants' longer search times brought on by the warnings of multiple hazards. This highlights the need to study the unique mechanisms involved in these errors during driving, following validation of these studies with dynamic hazard perception tasks. In basic SSM tasks, participants are thought to be depleted of processing recourses after refixating on the first target (Cain et al., 2013) and SSMs are known to be reduced if the first target disappears from the scene once it is found (Cain and Mitroff, 2013). The nature of these refixations will be an important consideration for future eye-tracking studies of SSMs in driving. It will also be important for eye-tracking studies in this area to distinguish between different consequences that identifying a first target may have. For instance, these future studies may be able to determine whether there is a cost in efficiency that results in poorer visual orienting or other decrements on appraising the second target (Huestegge et al., 2010). Based on the results of Adamo et al. (2017) individual difference approach to SSM errors though, one hypothesis is that appraisal (or "modulation"; Chun et al., 2011) will be most affected.

The experiments described in this manuscript provide the first step to understanding SSMs during drivers' visual searches. However, more work is needed to implicate SSMs as a contributor to hazard perception failure, as well as to better understand the fundamental mechanisms that contribute to this error. With support from these future studies, transportation researchers and traffic accident diagnosticians may find Subsequent Search Misses to be a prominent feature in motor-vehicle-accident investigations.

Conflict of Interest

Nothing declared.

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