

Better off Alone: The Presence of One Hazard Impedes Detection of Another in Simulated Traffic Scenes

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It is well known that traffic collisions can easily occur when a driver's attention is consumed by task irrelevant information (e.g. cellphone, or billboards). Is it possible though that drivers will fail to identify certain hazards or traffic signals because their focus is consumed by other, equally, pertinent events on the road? In order to answer this question, the present study adopted a simulated driver awareness task which used Satisfaction of Search to show that when drivers are faced with a single low-salience hazard, they will be significantly more likely to identify it than if presented alongside another high-salience hazard. The results indicated that highly salient objects may actually prevent drivers from being able to locate other targets on the road, regardless of their relevance.

With over a decade of research demonstrating a driver's inability to efficiently share attentional resources with distractions like cellphones (McCarley, Vais, Pringle, Kramer, Irwin, & Strayer, 2004), scientists have produced a wealth of life-saving information on driving behavior with the public. However, given that the issue of driver distraction seems to continue to challenge the safety of motor vehicle operators, cognitive scientists continuously seek to better understand the influences of this pervasive problem. Some research has suggested that distractions occur both voluntarily as well as involuntarily, and that susceptibility to involuntary distractions may stem from individual differences in cognitive limitations (Feng et al., 2014). Not only do differences exist in a drivers' ability to control their diversion of attention, there are also a number of different types of objects or events which maybe demanding of one's attention while on the road. Most are aware of how dangerous in vehicle distraction like cellphones and touch screen radios can be (e.g. Drews, Yazdani, Godfrey, Cooper, & Strayer, 2009), but drivers have also been known to become consumed with other irrelevant items occurring outside of the car, such as billboards (Megias, Maldonado, Catena, Di Stasi, Serrano, & Candido, 2011).

Studies which use principles from cognitive science to help improve and explain driver performance, are useful for a number of reasons. While it is incredibly valuable to understand the cognitive limitations that lead to distracted driving, emphasis on distraction from task-irrelevant objects may not sufficiently illustrate failures to attend to necessary stimuli on the road. Consider the following driving scenario: while driving in a highly cluttered environment, a person approaches an intersection with a pack of competitive cyclists partially occluding the path. Just after narrowly escaping these highly salient athletes, the driver designates the indented path to be safe and fails to notice the less-salient child

who is chasing his ball into a different part of the intersection. This series of events encapsulates what radiologists (Barbaum et al., 1996) cytologists (Bowditch, 1996), luggage screeners (Biggs, Cain, Clark, Darling & Mitroff, 2013), and cognitive psychologists (Fleck, Samei, & Mitroff, 2010) have come to call "Satisfaction of Search (SOS)," or "Subsequent Search Misses" Cain, Adamo, & Mitroff, 2013). More specifically, Satisfaction of Search describes a phenomenon studied with a visual search task that involves asking participants to locate targets in cluttered scenes. The participants are told that these scenes may contain up to two different targets simultaneously, which can either be of high or low salience. Researchers have found that participants have a relatively high frequency of low-salience target identification when those targets are presented by themselves. However, frequency of low-salience target identification then drops when they are presented in the same scene as a high-salience target (Fleck, Samei, & Mitroff, 2010). The original name of this visual search flaw, Satisfaction of Search, was likely chosen to encompass the hypothesized explanation in these dual-target scenes, whereby the observer would become content with the identification of the first high-salient target and decide to terminate that search. Evidence has shown this "satisfaction" explanation to be overly simplistic though (e.g. Cain, Adamo, & Mitroff, 2013). Rather, it is likely that the cause of this error involves a complex interaction between the observer's basic perceptual, sensory, and cognitive limitations, which could not be explained simply by stating that the person became "satisfied" with the search. Therefore, the current study has adopted the title "Subsequent Search Misses" (SSMs) put forth by Cain et al., (2013), in order to be more accurate in the explanation of this failure. Applied and theoretical research has provided at least some evidence to suggest that there are similarities

between SSMs and driving performance (vis-à-vis, visual search and hazard detection), and that the phenomenon may occur in traffic related situations. Much like a driver’s performance in hazard perception tasks, SSMs have been known to be influenced by anxiety (Cain, Dunsmoor, LaBar, & Mitroff, 2011; Machin, & Sankey, 2008), as well as training (Nakashima, Kobayashi, Maeda, Yoshikawa, & Yokosawa, 2013; Horswill, Taylor, Newman, Wetton, & Hill, 2013). Other real-world applications of abstract cognitive principles have also shown to remain when replacing basic and meaningless stimuli with complex and familiar traffic scenarios (Sall, Wright, & Boot, 2014). Therefore, it is possible that the perceptual limitations which lead to Subsequent Search Misses in basic laboratory experiments, luggage screening, and radiological offices, are also experienced by drivers who fail to notice objects or events on the road. To the best of the authors knowledge though, no research exists which directly demonstrates the presence of SSMs in the context of driving performance. The current study sought to demonstrate if detection of low-salience objects in cluttered simulated traffic scenes would be better when presented by themselves, compared to the same scenes that contained another high-salience object of interest.

and participants were compensated with credit for an introductory psychology course.

Apparatus & Stimuli

An original traffic perception task was developed in order to examine the potential for SSMs to affect driver performance. The stimulus presentation was structured similarly to Feng et al’s., (2015) *Drive Aware Task*, though the traffic scenes were developed in order to mirror the frequency of targets from previous laboratory experiments which have been known to elicit the SSM pattern (e.g., Fleck, Samei, & Mitroff, 2010). An example trial is illustrated in Figure 1. The experiment was built using E-Prime (Version 2.0, Psychology Software Tools, Pittsburgh, PA) on a PC with a 27-inch monitor (Dell, 60 Hz). Each trial began with a fixation cross presented at the center of the screen for 100ms, followed by an arrow for 1s. The arrows, which could have been pointing in one of three directions (pointing straight, left, or right), indicated the desired direction of travel in the following simulated traffic scene. The traffic scenes were created using SketchUp Pro 2016 (Version 16.0.1991.3 Mac 64-Bit, Trimble Navigation, Sunnyvale CA). Similar to Fleck et al., (2010), these real-world road-like scenes contained a varying number of distractors and targets which were presented amidst a visually cluttered environment (e.g. a busy city street or neighborhood in dense fog). Each scene contained either 0, 1, or 2 driving hazards (targets), with single target conditions containing either a high-salience or low-salience target. Dual-target conditions would always contain one high, and one low salience target. Targets were defined broadly as objects or events which would have directly

METHODS

Participants

Twenty undergraduate psychology students (8 males, 12 females) from a large university were recruited for the study. All subjects reported being licensed drivers and had normal, or corrected-to-normal vision. Informed consent was collected prior to experimentation

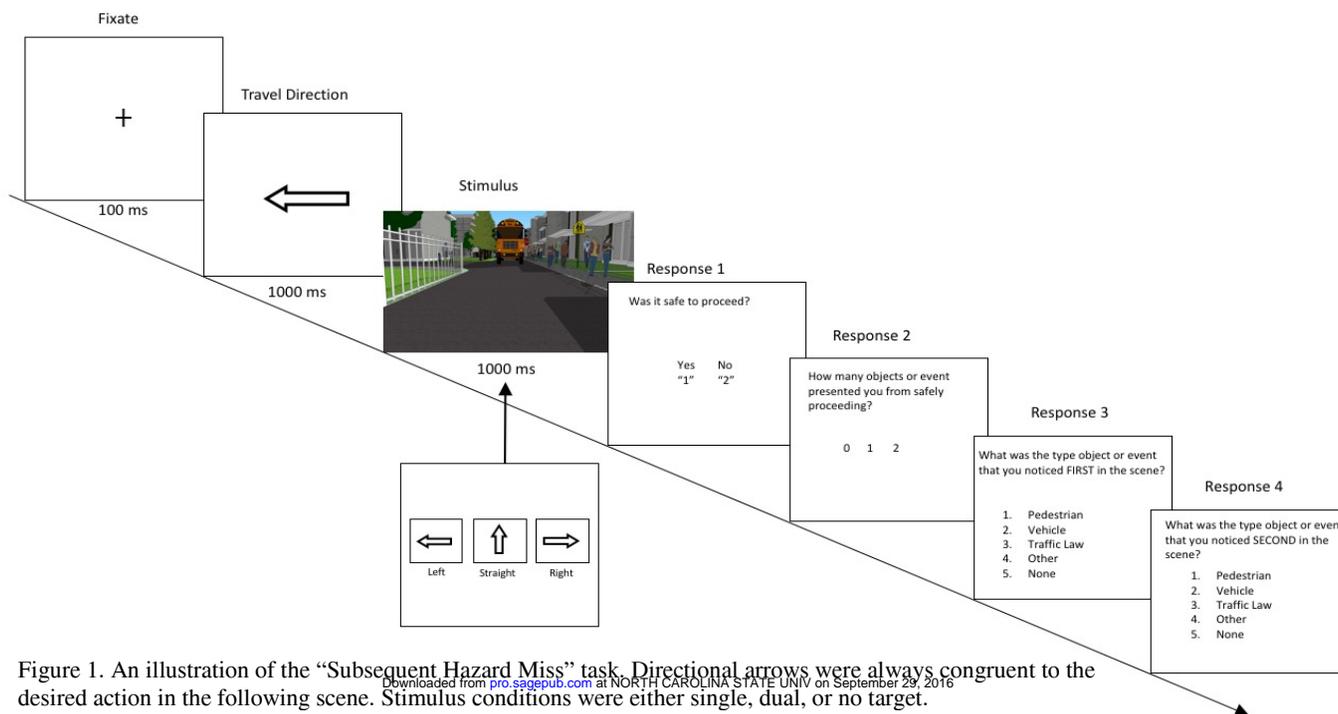


Figure 1. An illustration of the “Subsequent Hazard Miss” task. Directional arrows were always congruent to the desired action in the following scene. Stimulus conditions were either single, dual, or no target.

prevented or impeded safe passage in the direction intended by the arrow which preceded the image. Therefore, unlike classic visual search experiments, the singular difference between distractor and target items was the item's interference with the observers intended path. Like target items, distractors were also of either low or high salience. In total, participants viewed 100 traffic scenes during the experiment, each presented for 1s. The distribution of single high/low, dual, and no target conditions was taken from experiment 3 of Fleck et. al., (2010). 16 of them contained one low-salience target, and another 48 had a single high-salience target. 20 of the scenes had no target, and the other 16 were dual target conditions.

Saliency was manipulated by adjusting the level at which the item's features seemed to contrast with its surrounding (i.e. bottom-up salience; Itti & Koch, 2000) but target items were always those which were relevant to the observer's goal (i.e. controlling for top-down salience). While previous studies demonstrating SSMs tended to rely exclusively on the former of these two types of attention processing, the complexity and familiarity of driving has been shown to be influenced by both of these attentional processes (McCarley, Steelman, & Horrey, 2014). Furthermore, controlling for top-down salience of the target items was also important for distinguishing the root cause of a driver's inability to locate the low-salience item when presented along side its high-salient counterpart. That is, accurately being able to claim the perceptual flaw as being more closely related to the SSM phenomenon and not an *inattentional blindness* (Simons, & Chabris, 1999), whereby one goal relevant event prevents identification of another irrelevant object. Thus, both items in these scenes had similar relevance to the task.

Bottom-up salience was regulated using three criteria outlined by previous attention studies: color contrast, orientation and movement / direction. The first criterion for bottom-up salience was that items may have contained colors which were unique to their surroundings (i.e. a bright red fire truck appearing amongst a series of white cars; Treisman, 1985). The items which were considered to be highly salient could have also been oriented differently than surrounding items (Treisman and Gormican, 1988). For example, if several cars in one scene were facing one direction behind the stop line of an intersection, the high-salience item may have been presented at a 45° rotation from the others as it turned the corner. The final criterion for bottom-up salience was that the high-salience objects may have appeared to be traveling, or facing, in the direction opposite to the other objects in the scene (Nothdurft, 1992).

Procedure

After signing and collecting informed consent from the participants, researchers began the laboratory experiment. Their heads were then positioned in a headrest approximately 60cm from the computer screen. Subjects were informed that they would be presented with a number of traffic scenes, following an arrow pointing in one of three travel directions. Their instructions for the task were to quickly assess whether or not it was safe to proceed in the direction indicated by the arrow which preceded it. Following these scenes, they were asked to quickly answer a series of questions. All answers were collected using the computer's number key pad.

The first question merely asked whether or not it was safe to proceed. The second question asked how many objects or events would have prevented safe travel in the desired direction. The participants were told that in each scene there may have been 0, 1, or 2 target items or events which would have prevented them from continuing. They were not told, however, that the target items or events would have been of various saliency. The final two questions involved asking the participants to identify which types of object or event prevented their safe passage. Responses could have been 1 for vehicle, 2 for pedestrian, 3 for traffic law, 4 for other, and 5 for none. The instructions were to specifically identify the object or event they noticed first from the scene, in the first of the two identifying questions. Then, identify which object or event from the scene was noticed secondly in the second identifying question. So, if no objects were present, participants should have indicated "none" for both of the identification questions. Objects or events were defined broadly as anything which would have impeded safe passage in the intended direction.

Before beginning the actual block, participants underwent 12 practice trials to prepare them for the stimulus presentation and questions. The distribution of scene type was also similar to what would then be presented to them in the actual experiment. Following the practice, participants completed 100 scenes and divided into 4 blocks. Each block contained the same number of single, dual, and no target scenes, presented in random order. Given that the primary analysis focused on comparison of the single low target condition and the dual target condition, all 16 of the single low images were exactly the same as the dual scenes minus the second high-salience target in the latter. To prevent interference from memory of the scenes, a single low scene was never presented in the same block as its dual target parallel. The researchers also stipulated in programming the experiment that the first two blocks would contain the single low scene equivalents from the

dual scenes in the last two blocks, the dual target scenes from the single low in the last two blocks, and so on.

RESULTS

The primary analysis focused on participant’s accuracy of low and high-saliency targets across single and dual target conditions. A 2x2 repeated-measures ANOVA with trial type (single, or double) and saliency (high, or low) as within-participant factors was conducted for the primary analysis. There was a main effects for saliency, $F(1,19)=189.44, p<.001, \eta^2=.91$, as well as trial type, $F(1,19), 106.92, p<.001, \eta^2=.85$. Finally, a significant interaction was seen between trial and saliency, $F(1,19)=96.98, p<.001, \eta^2=.84$. Mean accuracy for high

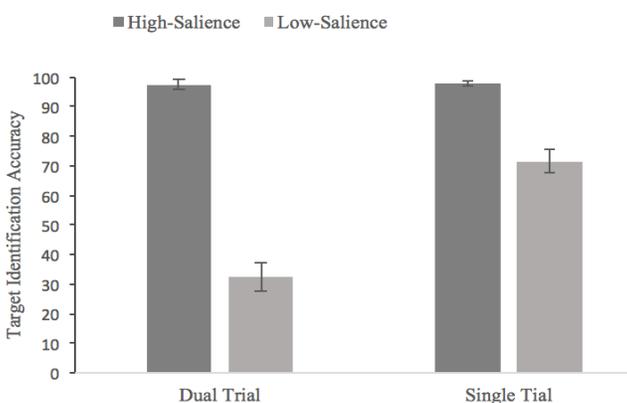


Figure 2. Illustrated ANOVA with trial type (sing, and low) and saliency (high, and low) as within-subject’s factors. Error bars represent Standard Error.

and low-saliency targets in both single and dual target conditions can be seen in Figure 2.

Initial contrast revealed a significant difference between high and low-saliency accuracy in single target conditions, $F(1,19)=54.02, p<.001, \eta^2=.74$, and dual target conditions, $F(1,11)=250.4, p<.001, \eta^2=.93$. This confirmed that the manipulations of saliency were valid, given that high-saliency accuracy was significantly higher in both trials than low-saliency accuracy.

Finally, consistent with the researcher’s hypothesis, further decomposition showed a higher accuracy for low-saliency target in the single trial condition than low-saliency targets in the dual target condition, $F(1,19)=119.89, p<.001, \eta^2=.86$.

However, the same was not found between high-saliency targets in the single and dual $F(1,19)=.78, p=.778, \eta^2=.04$ conditions.

DISCUSSION

Most conceptions of distracted driving will likely involve a person’s departure from processing task-relevant information in order to attend to an irrelevant stimulus. This study suggests though, that the processing of task-relevant traffic stimuli may actually impede a driver’s ability to attend to other task-relevant information. This effect of one target’s presence on subsequent hazard identification while driving is novel in that it offers some evidence which suggests a relationship between visual search flaws experienced by radiologists and those which affect drivers. Unique though it may be, these results provide no more than a foundation for this new perspective on the study of driving performance.

Future research which involves this new “Subsequent Hazard Miss” paradigm should adopt approaches which others have taken to studying the basic Subsequent Search Miss phenomenon. For instance, Cain, Adamo, and Mitroff’s (2013) taxonomy of SSMs involved eye-tracking to distinguish distinct mechanisms involved in these multiple target search errors. Future studies with the current traffic-related adaptation may find such a taxonomy to have staggering differences. One cause of Subsequent Search Misses that is likely to be more representative of errors in the newer Subsequent Hazard Miss task, are those in which an observer’s knowledge of the first (high-saliency) targets (Solman et al., 2011; Oh, & Kim, 2004) consume working memory resources. This consumption of working memory resources has been shown to prevent identification of the second target in basic Subsequent Search Miss experiments (Cain, & Mitroff, 2013). Given that driving requires working memory resources from more than just visual attention (Jonannsdottir, & Herdman 2013), it is likely that this type of error accounts for more than the roughly 25% of lapses made in basic SSM tasks (Cain, et al., 2013).

Another source of dual-target search errors that are and also likely to be represented more on the road are those resulting from an observers locating an item, but failing to recognize an item as a hazard. It is likely that these “recognition errors” (Cain, et al., 2013) may be overly represented in dual-target traffic searches because many hazards are only worth identifying because of their location. A child who chases his ball in the middle of a busy intersection is only considered to be hazardous once he lands in the driver’s path. In more abstract dual-target search tasks used to study SSMs however, a target is designated as such regardless of where it is located. It is possible that this extra component of processing may hinder a driver’s ability to identify dangerous items in the field of view.

Table 2. Average frequency of correct responses

	High-Saliency		Low-Saliency	
	Single	Dual	Single	Dual
Mean	98	97.57	71.57	32.36
SE	.76	1.56	4.63	3.81

The current study's methodology does present some limitations when suggesting the Subsequent Search Miss phenomenon as a limitation experienced by drivers. Other than the small sample size, the present study's use of static imagery in its measure of driving performance may lead one to question this study's validity. While similar tactics have been used before in studies of hazard perception (e.g. Scialfa, et al., 2012), it may cause concern that SSMs seem to have been primarily studied through a spatial-visual-search task, whereas the oncoming of traffic hazards appear temporally. However, eye-tracking data have revealed an *Attentional Blink*-like effect (Adamo, Cain, & Mitroff, 2013) in static SSM scenes. Attentional blink, an inability to process the second of two letters which are presented over a temporal stream (Raymond, Shapiro, & Arnell, 1992), in spatial SSM scenes lends itself to addressing the concern of construct validity for the current study by offering a connection between processing of the same stimuli through temporal and spatial planes.

In order to continue to improve traffic safety, researchers must expand the network of models used to study driving behavior. One of the aims of the current research was to develop a new paradigm under which researchers would be able to further understand performance in cluttered traffic environments which normally consists of more than one safety-critical target. The study was also successful in supplying early scientific evidence to suggest that highly salient task-relevant information on the road may inhibit processing of subsequent hazards when they are presented simultaneously. Despite the robust effects on hazard detection seen in this study though, further research into the nature of visual search in traffic scenes is still needed.

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