Destination, Seen Unclearly: Relevance of Head-Up Display Information to Driving Is Unrelated to Its Processing

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Studies have shown that secondary information presented in spatially commingled environments along with primary tasks can adversely affect the performance of that task, as might be the case for information delivered to drivers by a Heads-Up Display (HUD). However, it is unclear how that message's relevance to the task at hand (e.g., driving) might impact either detection of that message, or performance of a primary task. In this study, participants were asked to enumerate cars on a screen in an experiment that sporadically presented them with semantically similar and dissimilar pieces of information in a spatially intermingled environment. The results indicate that when occupying the same spatial proximity as the primary stimuli, all secondary stimuli disrupt primary task performance, regardless of its relevance to the primary task.

A prevailing ambition for many transportation laboratories is research attempting to understanding why a driver might fail to identify objects on the road, whether they be an unanticipated hazard, or a common traffic signal. In order to do so, many have called upon theoretical paradigms from the cognitive sciences (e.g., Groeger, 2000; Mathias, and Lucas, 2009). One piece of work that has drastic implications for the limitations of the human attentional system while driving is that involving the inattentional blindness paradigm (Simons and Chabris, 1999; Strayer and Drews, 2007). This phenomenon, which remains a staple for introductory psychology courses, is perhaps best known by its ostentatious demonstrations that have involved failures to see dancing gorillas (Simons and Chabris, 1999), pictures of apes in medical images (Drew, Võ, and Wolfe, 2013), and even staged street fights (Chabris, Weinberger, Fontaine, and Simons, 2011). As whimsical as these studies may appear, this paradigm describes one of the most prolific phenomena in cognitive psychology. That is, humans have a major limitation in their ability to see, often very salient, pieces of visual information. Even more surprising is that fixations on missed stimuli in these studies do not predict whether or not a person sees them (Beanland and Pammer, 2010).

In a more recent demonstration of inattentional blindness, Sun and colleagues (2015) asked participants to enumerate black circles on a screen while unexpected stimuli occasionally appeared in the same spatial locations as the circles. In this study, the authors demonstrated that one's ability to enumerate these simple shapes is compromised greatly by the presence of a secondary stimulus in a spatially commingled visual field. Furthermore, the time taken to process the primary stimuli was greatly extended when participants were asked to identify the second image that appeared. The researchers go on to generalize their findings regarding potential safety concerns for drives of augmented reality heads-up displays (AR-HUD), as well as the efficacy of those devices in their ability to deliver information. Specifically, it was proposed that in-vehicle messages delivered by HUDs would likely go unnoticed, depending on the level of cognitive demand put in place by the driver's environment (e.g., a driver on a busy road would be less likely to notice an alert from a HUD).

While the importance of those data does hold great relevance for those concerned with driver safety, as well as HUD manufacturers concerned with the utility of their devices, there are several important characteristics of this study that were not accounted for in the original experiment. For example, it was not determined how the relationship between information being delivered by the device and the driver's primary objective might impact one's ability to detect those messages. In other words, it is possible that secondary information that is related to driving (e.g., speed, directions), and presented in the same spatial field as objects of the primary task, may be processed more efficiently by drivers than HUD information that is completely irrelevant to the driver's primary task (e.g., text messages).

Lessons surrounding the general limitations drivers face when trying to divide attention (e.g., Strayer, Drew, and Johnston, 2003) suggest that it is likely that both types of stimuli will reduce performance of a primary task in the aforementioned scenarios. However, it is important to determine how a secondary stimulus' relevance to the primary task will influence its ability to be identified, given that HUD manufacturers have begun to incorporate task-irrelevant information into their devices (NAVDY, 2017; as illustrated in Figure 1).

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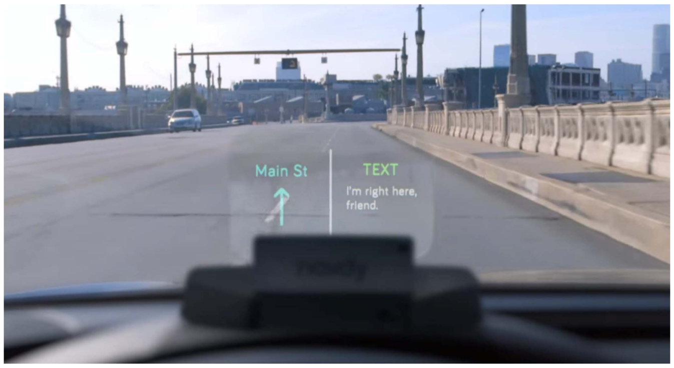

Figure 1. *Example of the different types of information relevance used by HUD devices (NAVDY, 2017).*

The literature has provided some indication that increased perceptual similarity between secondary and primary stimuli as a factor that might reduce inattentional blindness (Most, Simons, Scholl, Jimenez, Clifford, and Chabris, 2001), and improve primary task performance in spatially sparse and dynamic situations (i.e., multiple object tracking; Welk, Creager, and Gillan, 2014). At least one inattentional blindness study has also shown that semantically similar secondary items will have higher detection and recognition rates than semantically dissimilar items (Koivisto and Revonsuo, 2007). This research has also been previously extended to transportation studies, where it was shown that a driver's likelihood of identifying secondary information (i.e., motorcycle) was increased if the secondary item was perceptually similar to the driver's *attentional set* (Most, and Astur, 2007). The purpose of the current study was to test how semantic relevance between primary and secondary task items in spatially commingled visual environments will affect identification of the secondary stimulus (i.e., inattentional blindness) as well as primary task performance.

Methods

Participants

Twenty-nine undergraduate students (12M, 17F; M_{age}=19.52, SD_{age}=2.60), were recruited from an introductory psychology class at North Carolina State University for participation in this study. All participants reported being licensed drivers with normal, or corrected-to-normal vision. Informed consent was collected before the experiment began.

Apparatus & Stimuli

The experiment was presented with E-Prime (Version 2.0, Psychology Software Tools, Pittsburgh, PA) on a PC with a 27-inch monitor (Dell, 60 Hz). The primary stimuli, to be enumerated in the experiment, were car icons picked from Snodgrass & Vanderwat's (1980) set of standardized picture icons, appearing at 1°x .5°. The secondary stimuli had one of the two three-letter words ("BUS", "BED"), appearing in black, and

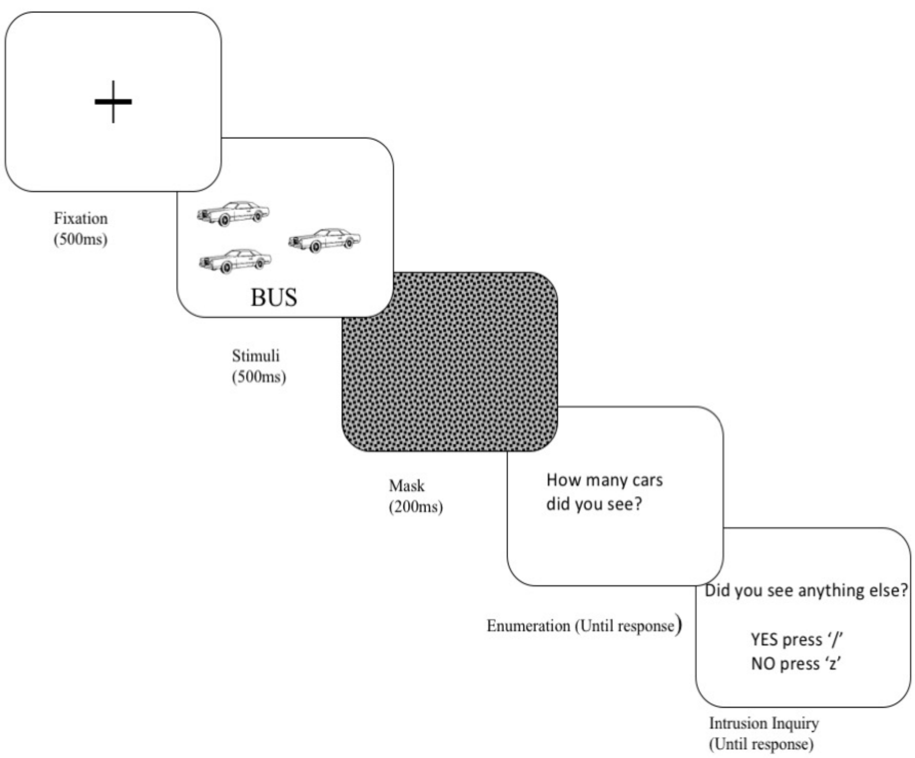

Figure 2. *Sequence of stimuli from an iterated trial. The above stimuli image is not to scale.*

subtending 1° x .5°. The positions of all stimuli (primary and secondary) were presented within a centrally-located 26° x 17° invisible area on the display. A headrest was used to maintain the viewing distance of 60cm during the experiment and participants made responses with the numeric pad on the computer's keyboard.

Procedure

Our task procedure was similar to Sun et al., (2015). The experimental session consisted of three phases, differing only in the frequency of secondary stimuli presented. Each trial began with a fixation cross, followed by display which contained a random number of car icons (1,2,3,4,5,7 or 8 icons), with an equal probability for each number of primary stimuli (i.e., cars) to be presented. The instructions given to participants were to identify the number of cars presented in each stimulus display. Trials all began with a central fixation cross presented for 500ms, which was immediately followed by the stimulus display. The stimulus display was presented for 500ms and proceeded a 200ms mask. Following the mask, a response display appeared where participants could report the number of icons (e.g., cars) in the stimuli display. The experiment began with seven practice trials to familiarize participants with the experiment, then seven initial enumeration trials.

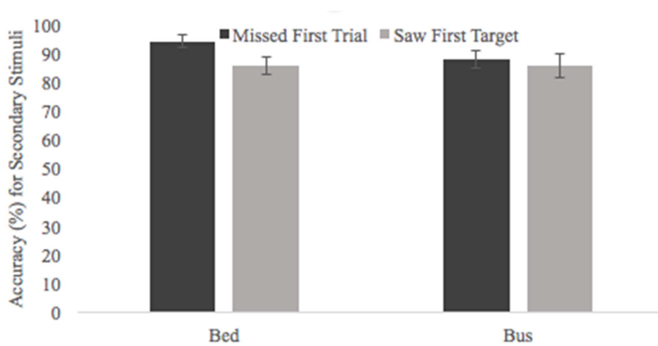

Figure 3. *Graph of enumeration accuracy (%) for all trials with secondary stimuli present, and absent. Error bars represent +/-1 standard error of the mean.*

On the seventh trial, participants were presented with their first inattentional-blindness condition (i.e. the last of the initial trials). In addition to the cars in this condition, the word "BUS" appeared and participants were asked to respond to the following prompt: "Did you see anything else? Press '/' for Yes and 'z' for No."

Iterated Trials

Once participants had completed the practice and first seven initial trials, 161 iterated trials were completed. Once again, participants were told that their task was to report the number of car icons that appeared in each trial. For each stimulus display, the number of cars to appear would vary with an equal probability of 1,2,3,4,5,7, or 8 cars presented. Secondary stimuli (e.g., "BED" or "BUS") could have appeared with .075 probabilities. Here, one of two different targets had an equal probability of being presented. Secondary stimuli were either a semantically similar word "BUS," or semantically dissimilar word "BED" (each with .0375 probabilities of appearing). Unlike the first phase however, participants responded with the secondary stimulus probe after each enumeration.

Full-attention Trials

Finally, participants underwent a series of full-attention trials, a common practice in inattentional blindness studies. These nine trials involved participants only reporting the presence of the secondary stimulus, and were intended to verify that the secondary stimuli presented were visible to participants.

Results

Overall enumeration accuracy was relatively high (*M*= 83.29, *SE*=.02). Descriptive statistics for frequency of secondary stimuli identification can be found in Table 1.

The primary focus of this study was to determine whether or not a semantically dissimilar secondary stimulus would be more difficult to detect during an enumeration task. However, it was also of interest to determine whether or not detection of the secondary stimulus in the homogeneous initial inattentional blindness trial would mean a difference in performance for secondary stimuli identification during the iterated trials. To answer this question, a 2x2 repeated measures ANOVA was carried out with secondary stimulus accuracy ("BED" or "BUS") as a within-participant factor, and initial secondary stimulus accuracy (detected, or not detected) as the between-participant factor.

Overall, detection of the secondary stimulus in the first trial was relatively low (*34% detected*). The results of the ANOVA revealed no significant effects. First, the main effect for secondary stimulus identification in the iterated trials was not significant, $F(1,27)= .96$, $p=.336$. Furthermore, there was no significant interaction between the secondary stimuli ("BED" or "BUS") and target detection in the initial trial, $F(1,27)= .96$, $p=.336$.

Table 1. *Average accuracy for secondary stimuli.*

	Missed First Trial		Saw First Trial	
	Bed	Bus	Bed	Bus
Mean	93.99	87.97	85.71	85.70
SE	2.24	2.99	3.09	4.13

While identification of the secondary stimulus was of primary interest, the ways that the different secondary stimuli may have impacted performance on the primary task was also noted. A separate repeated-measures ANOVA was conducted for the three, within-participant variables,levels of response time (trials with "BED" present, trials with "BUS" present, and trials with no secondary stimulus present). This revealed an overall main effect across the three levels, $F(2,56)= 63.59$, $p<.001$. A closer look though, demonstrates non-significant differences of enumeration accuracy when "BED" or "BUS" were presented, $t(28)=.07$, $p=.942$, but robust differences between secondary stimulus-free enumeration trials from those with "BED," $t(28)=11.70$, $p<.001$, or "BUS," $t(28)=11.02$, $p<.001$ (conducted with Bonferroni correction; see Table 2). In other words, accuracy on the primary enumeration task was compromised during trials when either secondary stimulus was present.

Table 2. *Average accuracy (%) for primary (enumeration) task across three trial types.*

	With Bed	With Bus	No Secondary
Mean	47.78	47.41	87.34
SE	3.42	3.42	1.76

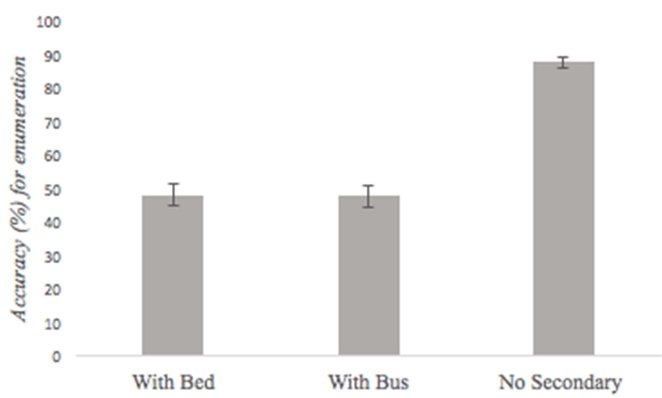

Figure 4. *Enumeration accuracy (%) across three trial types, during the initial and iterated trials.*

In addition to accuracy, reaction time was also analyzed as an alternate determination of performance during this task. A grand mean was calculated for time taken to enumerate, as well as determining the presence of a secondary object, and those data were entered into another repeated-measured ANOVA. This revealed a strong main effect for the three trial types (i.e., "BED" present, "BUS" present, and no secondary stimulus present), $F(2, 56)=7.29$, $p<.001$.

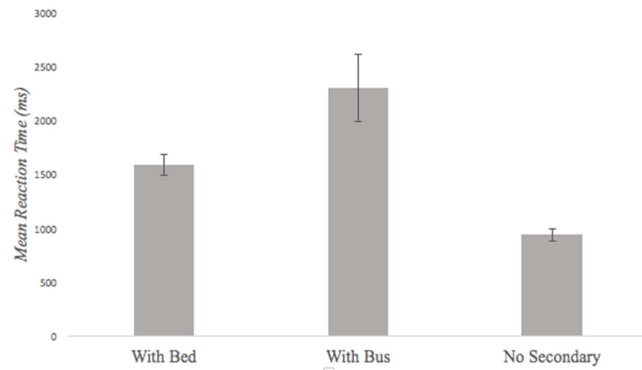

Figure 5. *Mean reaction time for enumeration, as well as detection of the secondary stimulus.*

Post-hoc comparisons (made with Bonferroni correction) demonstrated significant differences between all three groups, with the largest between mean reaction time for "BUS" present trials and no secondary stimulus trials, $t(28)=4.61$, $p<.001$. Staggering difference were also found between "BED" present, and "BUS" present trials, $t(28)=2.57$, $p=.016$, as well as "BUS" present and no secondary stimulus trials, $t(28)=10.48$, $p<.001$.

Table 3. *Average reaction time (ms) across three trial types*

	With Bed	With Bus	No Secondary
Mean	1585.84	2291.40	938.21
SE	93.22	310.33	55.18

Discussion

On the surface, the story told by these data is one that has been told by countless studies of distracted driving. That is, the attentional demands imposed on drivers consistently exceeds their attentional limitations. Arguably the most notorious examples of this are from voluntary engagement in distracting activities like use of mobile devices (e.g., Collet, Guilot, and Petit, 2010), though there has also been evidence for drivers' attention becoming compromised by roadside advertisements (Crundell, Van Loon, and Underwood, 2006), as well as red light running camera flashes (Sall, Wright, and Boot, 2014). More recent studies have also begun to demonstrate that drivers' attentional constraints behind the wheel are so limited that highly salient hazards may consume attentional resources to an extent that they might prevent drivers from locating other hazards in the same scene (Sall and Feng, 2016).

Digging a bit deeper than this superficial interpretation one finds a slightly different story. These data now present manufacturers with both an *ethical* conundrum of whether or not they should continue to build these devices, but also a *practical* consideration for use of HUD. Speculation, coupled with support from previous studies (Koivisto and Revonsuo, 2007; Most and Astur, 2007), may have previously led some to posit that HUDs presenting only information that is relevant to the driver's objective would be an efficient way to deliver information, at least in comparison to the delivery of unrelated information (e.g., text messages). While identification of the secondary target did not appear to be greatly impacted by its relevance to the primary task, reaction time did seem to be even more compromised by the presence of a semantically similar secondary target. One explanation for this is that rather than participants being "blinded" by the primary task, it may have created a strong top-down bias for which they would have been more likely to have their attention captured by similar objects. Theoretical evidence for this explanation is supported by the *contingent capture* hypothesis (Folk, Remington, and Johnston, 1992), which describes stronger involuntary shifts of attention when participants are briefly flashed irrelevant stimuli that fit into the *attentional spotlight* created for the primary task. In other words, while the semantic similarity between the secondary stimulus "BUS" and the primary task may not have led to any differences in the rate with which it (or the "BED") was identified, the similarity may have delayed processing for the primary task.

In light of these findings, manufacturers of automobile devices may want to consider alternative means of communicating essential information to drivers. A caveat to these findings is that accuracy for detecting secondary stimuli was relatively high in all conditions. However, it is likely that the repetition of the *intrusion inquiry* (i.e., question asking about the secondary stimulus) might have raised participants' expectation for the presence of the secondary stimulus.

Interesting though these findings may be, they are not without limitation. First of all, the differential demands imposed upon actual drivers and undergraduate psychology students counting cars on a computer screen limits the generalizability of this study. However, given that an actual driver will likely need to manage attention that is divided across many other objects and spaces, it is likely that this trend will remain or even increase.

Another problem with the current experiment is that the initial divided attention trial always presented the semantically relevant word. While this would have likely made detection of the word "BUS" even better by helping to refine participants' conceptual set, at least according to the literature, it did not appear to have much of an impact here. With that in mind, resolution of the hypothesis tested in this study was merely one of several that should be pursued in order to determine the true risk or benefit that HUDs present to drivers.

Once again, technological advances becoming burdensome to drivers is one of the most well known lessons learned by attention research in the transportation domain. The authors of this manuscript hope to add some validation to the potentially harmful nature of such devices, while also informing manufacturers of a possible need to improve the efficiency in the delivery of secondary information to drivers.

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