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Perceptual Load Induces Inattentional Blindness in Drivers

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Summary: Perceptual load theory states that the level of perceptual load in a task predicts the processing of task-irrelevant information. High perceptual load has been shown to result in increased inattentional blindness; however, there is little evidence that this extends beyond artificial computer-based tasks to real-world behavior. In this study, we adapted a typical load-blindness paradigm for use in a driving simulator. Forty-two drivers performed a series of gap perception tasks where they judged if their vehicle could fit between two parked vehicles, with the task imposing either low or high perceptual load. Awareness for an unexpected pedestrian or animal at the side of the road was found to be significantly lower in the high perceptual load condition. This study is the first to demonstrate perceptual load effects on awareness in an applied setting and has important implications for road safety and future applied research on the perceptual load model.

INTRODUCTION

Perceptual load theory suggests that when the current task places a high demand on attention, the processing of task-irrelevant stimuli can be prevented (Lavie, 1995; 2005). Specifically, when the perceptual load (i.e., the amount of information that must be processed) in the current task is high, all attentional capacity is exhausted and early selection takes place. This is in contrast to a task where perceptual load is low, when task-relevant and task-irrelevant stimuli are processed simultaneously, and late selection must take place to prevent distraction. Therefore, processing of irrelevant stimuli can be prevented under high perceptual load, resulting in reduced distractor interference.

Perceptual load theory was initially proposed as a possible resolution to the 'early vs. late selection' debate. This debate had dominated the field of attention for many years and centered on the question of how (and when) the selective part of selective attention takes place. How is relevant information selected over irrelevant information? 'Early selectionists' argued that distractors are rejected at the initial stages of visual processing because of capacity limits (e.g., Broadbent, 1958; Sperling, 1960). They suggested that because of our limited processing capacity, only relevant information is processed, and irrelevant information is filtered out at an early stage. 'Late selectionists', however, posited that perception has an unlimited capacity and it therefore processes all available stimuli at the early stage, before selectively prioritizing relevant information at a much later stage (Deutsch & Deutsch, 1963; Eriksen & Eriksen, 1974). In a 1984 study, Kahneman and Treisman (1984) investigated the body of evidence for each claim and found important methodological differences between the experiments supporting each viewpoint. Studies that found evidence for early selection seemed to use filtering paradigms—where participants are presented with a large amount of information, both relevant and irrelevant, and asked to perform a complex task (e.g., Cherry, 1953). However, studies that found evidence in support of late selection seemed to use selective set paradigms—where participants are presented with a small amount of stimuli and asked to perform a simple task (e.g., Posner, 1980). Building on this distinction, Nilli Lavie and colleagues put forward perceptual load theory as a potential resolution (Lavie, 1995; Lavie, 2005; Lavie & Tsal, 1994). Load theory states that perceptual capacity is limited but that perception proceeds automatically until that capacity is filled.

Support for the model has been derived from various response-competition paradigms, such as flanker tasks (Eriksen & Eriksen, 1974). In such a task, participants are required to identify a target stimulus (e.g., the letter X or N), which is presented in a circle of letters (e.g., Lavie & De Fockert 2003; Lavie & Cox, 1997). The search task may be low load (e.g., the circle contains one letter or all non-target letters are O's) or high load (e.g., the circle contains seven letters or all non-targets are similar to the target, such as K, M, W, T, and H). While performing the task, participants must ignore a distractor stimulus that may be compatible with the target (e.g., an X when the target is an X) or incompatible with the target (an X when the target is an N). Generally, responses are slower in incompatible relative to compatible trials. This occurs under low perceptual load and indicates that participants have processed the to-be-ignored stimulus and are suffering from distractor interference effects. This is because of response competition; if participants process the incompatible distractor along with the target, they have two potential responses competing with each other, and the irrelevant distractor must be actively suppressed. This process takes time, and hence, response times are increased. However, in line with the perceptual load model, this interference by incompatible distractors is eliminated under high perceptual load, suggesting that early selective attention has occurred. The incompatible distractor is not processed; there is no competition, and so, response times are faster. There is also a body of neuroimaging evidence to support the claims of the model, with studies finding reduced neural response to irrelevant distractors under

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high load using fMRI (O'Connor et al., 2002; Yi et al., 2004) and electroencephalograph (Parks, Beck & Kramer, 2013; Rees, Frith & Lavie, 1997).

While studies using this paradigm rely on indirect measures of distractor processing (target response time, neural activity), there is also evidence that perceptual load affects awareness. The typical 'inattentional blindness' paradigm requires a participant to complete an attention task (such as counting the number of passes made by a basketball team). During the experiment, an unexpected, task-irrelevant object (such as a woman with an umbrella) appears, clearly visible on screen (Mack & Rock, 1998; Simons & Chabris, 1999). Participants are asked to report whether they were aware of any extra objects during the trial. Many participants fail to report awareness of the object, although in a control trial, where they are not engaged in a central task, they are able to see the object. These errors are therefore said to be indicative of a failure to attend to the object—inattentional blindness. CArtwright-Finch and Lavie (2007) found that perceptual load was a significant factor in predicting awareness of the critical stimulus (CS). They adapted a typical inattentional blindness paradigm to incorporate a load manipulation. Participants were presented with a cross and had to indicate which arm was blue (low load) or which arm was slightly longer than the other (high load). Participants performed a number of trials, and on a final, critical trial, an unexpected black square was presented on screen along with the cross. Rates of awareness for the unexpected object were significantly reduced under high load (typically 40–50% lower). Remington, Cartwright-Finch, and Lavie (2014) replicated this experiment and found similar results when the subjects were children (although children required a smaller increase in load to induce inattentional blindness, because of their reduced perceptual capacity) and when the target stimuli were presented in the same range of peripheral locations as the critical stimuli, suggesting that the effect is not merely due to a spatial focus on fixation, which excludes the periphery. Macdonald and Lavie (2008) also found similar evidence for load-induced blindness using the classic letter-search paradigm and presenting an unexpected object (a meaningless gray shape) in a random subset of trials. Their results held across a number of experiments, even when they introduced a 2-second delay between the array presentation and response to the task, when participants responded to the CS immediately (before they responded to the search task, rather than after, as was the case in the other experiments), and when the CS was presented more frequently (on 50% of trials) and was therefore more likely to be prioritized. These alterations to the traditional paradigm support the conclusion that inattentional blindness under high perceptual load is driven by an attentional capacity mechanism, not due to failures of other cognitive processes such as memory or goal maintenance.

While these studies are important for understanding the effect of load on awareness, they are artificial tasks, somewhat divorced from real-world attention. Does this effect extend to real-life inattentional blindness? There is a lack of applied support for the perceptual load model with much of the evidence arising from artificial paradigms (Furley, Memmert, & Schmid, 2013). Research has shown that inattentional blindness can occur in everyday tasks, such as failing to report awareness of a clown on a unicycle when walking and talking on the phone (Hyman et al., 2010). However, there have been no studies investigating the role of perceptual load on such real-world inattentional blindness. In the current study, we have chosen to investigate perceptual load and inattentional blindness in drivers, as driving is a task where attention is critical and failures are costly. We will adapt the cross-task paradigm for use in a driving context, presenting drivers with a gap perception task. Drivers must assess a lateral separation between two parked vehicles and determine whether the gap is large enough for the driver's car to pass through. The gap may be obviously too small or big enough (low load) or slightly too small or just large enough (high load). We will then assess awareness for an unexpected object (a pedestrian or a large animal) during low-load and high-load trials. This is a simple, direct translation of the existing paradigm to a real-world setting. We hypothesize that, in line with load theory, drivers will be less likely to notice the unexpected pedestrian under high perceptual load. Such a result would strengthen the perceptual load model of selective attention, providing real-world evidence that perceptual load in a central task affects awareness of additional stimuli.

METHOD

Participants

Forty-two drivers (20 male) were recruited for this experiment as part of a larger study. The mean age was 24.07 years (SD = 5.19). Participants all held driving licenses and had been driving for an average of 5.7 years (SD = 4.8). All participants provided informed consent, and the experimental protocol was approved by the University College Cork School of Applied Psychology Ethics Committee.

Apparatus and stimuli

The experiment was run in University College Cork's Driving Simulator Laboratory, using STISIM software (stisimdrive.com). The lab consists of a full-size five-door manual drive Volkswagen Polo surrounded by floor-to-ceiling screens. LCD screens in the wing mirror and a projection screen behind the car create a fully immersive experience. Drivers have full use of the gears, pedals, speedometer, tachometer, and other vehicle controls.

The experimental drive consisted of a series of gap perception tasks, spread along a straight, barren road. For each trial, six vehicles appeared in front of the driver, the closest being 60 ft away. There were three vehicles on either side of the road, with a gap in between. Participants had to determine if they could fit through the gap, using the vehicle's indicator to indicate left if they could pass through it and indicate right if it was too narrow. They were instructed to indicate as quickly and accurately as possible. They then had to act on their decision, either driving through the gap or passing around the vehicles to the right. The driver's vehicle was 4 ft wide. The low-load trials had gaps that were obviously very large (M = 8.33 ft, SD = 0.56) or very small (M = 2.05 ft, SD = 0.72), while the high-load trials were slightly too small (M = 3.6, SD = 0.2) or just big enough (M = 4.5 ft, SD = 0.21; Figure 1).

Figure 1. A low-load, critical trial with the unexpected pedestrian visible to the left. This is a 'pass-through' trial in which there is sufficient space for the driver's car to pass through the gap

Procedure

Participants first completed a 10-minute practice drive, during which they were encouraged to explore different speeds and maneuvers so as to get used to the vehicle and the controls. Participants completed 20 practice trials and 70 experimental trials. Low-load and high-load trials were randomly intermixed, and they were equally likely to be 'pass-through' or 'go around' trials. On trial 35 and trial 70, an unexpected object (a pedestrian or a large animal) appeared along with the vehicles, standing on the grass verge on either the left or the right side of the road. One of these critical trials was a low-load task and one was high load. The order in which the low-load and high-load critical trials were presented, the order of the two unexpected objects, and the side of the order of the left and right sides of the road were all counterbalanced across participants. Participants were asked immediately after the critical trial if they had seen anything different in that trial. They did not receive feedback on their performance. At the end of the experiment, drivers were presented with the two critical trials again, this time without completing the gap perception task. Any drivers who did not see the critical stimuli on these trials were discounted from analysis.

RESULTS

One participant was removed from the analysis, as they did not report awareness of the critical stimuli during the control trials. For the remaining participants, mean response time and accuracy were calculated for low-load and high-load trials.

Gap perception task

Response times

A paired *t*-test revealed a significant effect of load on response times, $t(40) = -4.49$, $p < .001$. Drivers responded more quickly in low-load trials ($M = 993$ ms, $SD = 219$ ms) than high-load trials ($M = 1129$ ms, $SD = 370$ ms).

Accuracy

A paired *t*-test also indicated a significant effect of load on the number of incorrect responses in the gap perception task, $t(40) = 2.36$, $p < .05$. Low-load trials were more accurate ($M = 98.6\%$, $SD = 2.1\%$) than high-load trials ($M = 97.8\%$, $SD = 3.5\%$). Both conditions had high average accuracy, with all participants making very few errors.

Collisions

Drivers collided with parked vehicles more often in the high-load gap perception trials ($M = 1.36$ crashes, $SD = 1.66$) than the low-load trials ($M = .14$ crashes, $SD = .42$), $t(40) = -4.7$, $p < .001$.

Critical stimulus awareness

Each participant was presented with two critical trials. Half of the participants saw the high-load critical trial first and half saw the low-load critical trial first. Any critical trials where participants responded incorrectly to the gap perception task would have been excluded; however, all participants correctly responded to the critical trials. An exact McNemar's test determined that there was no difference between awareness rates in the first ($M = 66.7\%$ correct, $SD = .48$) and second ($M = 64.3\%$ correct, $SD = .49$) critical trials, $p > .05$, suggesting that expectancy did not affect performance. McNemar's test can be described as a within-subjects chi-square analysis and was appropriate in this instance as the data were categorical (yes/no) and repeated within subjects. Participants were considered aware of the CS if they reported seeing a person or object on the correct side of the road. As can be seen in Figure 2, load had a clear effect on awareness. Twenty-two out of 41 participants saw the CS under low load, compared with just seven out of 41 under high load, χ^2 $(1, n = 41) = 17.78$, $p < .001$.

DISCUSSION

This study provides evidence that the effect of perceptual load on awareness can generalize beyond artificial letter-search tasks, to complex, real-world behavior. Varying the level of perceptual load in a gap perception task had a significant effect on awareness for a pedestrian at the side of the road. Drivers commonly perform gap perception tasks, especially during urban driving—for example, determining whether one can safely pass another car on a narrow street. This novel paradigm therefore illustrates how load theory can be applied to everyday tasks. The results of this study support load theory, finding that the level of load in a central task affected processing of peripheral, but potentially important, stimuli. There is not a great deal of evidence that load theory can be applied to real-world behavior, and so, this study

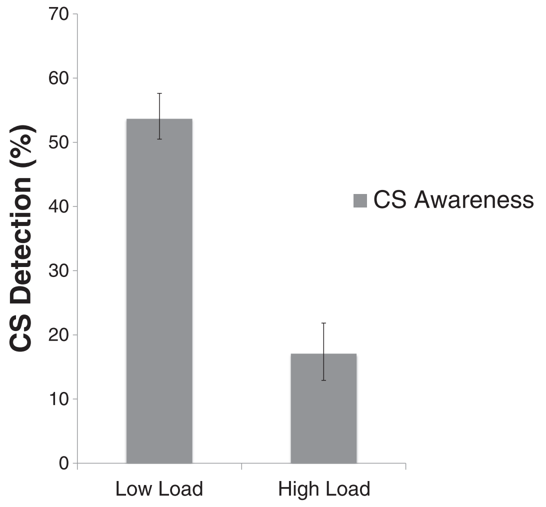

Figure 2. Percentage of participants who indicated awareness of the critical stimulus (CS) under low and high perceptual load, with 95% confidence intervals shown

represents an important step for the model. Surprisingly, participants made few errors in the gap perception task, even in the high-load trials with a total error rate of just 2.2%. Participants all had driving licenses and had been driving for more than 5 years on average. This experiment was also conducted in a university in the second largest city in Ireland, which contains many narrow streets with roadside parking. It is likely therefore that our participants had had much practice with gap perception tasks before and that may explain the high accuracy levels. It is, however, interesting that a task that participants performed so well, with so few errors, still affected their awareness of the CS to such a degree. Importantly, for road safety, this study suggests that inattentional blindness can occur before driving skill begins to noticeably deteriorate. The level of perceptual load in the current task was sufficient to blind drivers to a roadside pedestrian, and yet, very few incorrect gap perception decisions were made, so drivers were likely unaware that they had reached the limits of their attention capacity. This is in line with load theory, which suggests that while high perceptual load tasks can be performed perfectly well, it is additional information that is affected by the load imposed by the central task.

Despite participants' driving skill, the level of inattentional blindness observed in this study was relatively high, with just over 53% of drivers reporting awareness of the CS under low load and 17% under high load. This is in line with previous computer-based studies such as that of CArtwright-Finch and Lavie (2007), where awareness for an unexpected stimulus was 55% under low load and 10% under high load. The authors suggested that the low level of awareness was likely due to the marked difference in size and shape between the target stimulus and the CS. They found that in a second study, where the target and CS were the same color and size, awareness increased considerably under low and high load (to 88% and 50%, respectively). As roadside pedestrians ought to be a particularly salient stimulus for drivers, one might expect awareness under low load in the current experiment to be much higher; however, inattentional blindness in a simulated driving task appears to mirror that observed in artificial computer search tasks. This is certainly important for road safety purposes, although it must be noted that the consequences of missing a pedestrian in a driving simulator task are very different from the real-world equivalent and that may have impacted drivers' performance. It is, however, interesting for load theory researchers to note that such a direct translation of basic research to an applied context can produce almost identical results. Although load theory has been criticized for being overly reliant on artificial paradigms divorced from real-world attention (e.g., Furley, Memmert, & Schmid, 2013), it appears that the model is robust enough to function in applied contexts. This is promising as there are a great number of settings where attention is crucial and load theory could be used to improve performance, such as education, health care, and sports. Future research ought to consider other applications of load theory paradigms to real-world tasks. Such research strengthens the model by providing evidence that these cognitive processes do influence behavior in our daily lives, as well as providing evidence-based suggestions to improve the world around us.

The results of this study provide evidence that perceptual load impacts driver behavior and awareness, even during simple driving tasks such as gap estimation. Perceptual load should therefore be taken into consideration by drivers and other road users, as well as those designing roads. We manipulated load via a driving maneuver; however, perceptual load may also vary because of environmental factors (e.g., road layout, signs, and traffic). Future research should investigate the effect of this type of load on driver behavior. It would also be interesting to investigate if the results of this study could be replicated with a moving pedestrian. A pedestrian crossing the road ahead may be more salient for a driver than a pedestrian standing still; however, there is evidence that inattentional blindness can also occur with moving stimuli (Most et al, 2001; Simons & Chabris, 1999).

The current research has investigated the effect of visual perceptual load on inattentional blindness; however, there is some research that suggests that perceptual load can have cross-modal effects. Macdonald and Lavie (2011) found that visual load from a cross task can result in inattentional deafness, where individuals fail to detect a clearly audible tone. The effect of visual load on driver awareness for auditory stimuli and the effect of audio load on driver's visual awareness represent interesting avenues for future research.

The effect of perceptual load on driving represents a clear and important application of load theory to real-world behavior. We hope that the current study will be the first of many such applications of load theory, as we believe that it is a model that could and should be used to examine and improve performance in many domains.

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