Abstract: An experiment was designed to test working memory on drivers’ endogenous control of attention. Studies in simple laboratory settings showed that working memory was crucial for maintaining task priorities and attention to relevant stimuli. A modified Posner’s cue-target paradigm, consisting of spatially predictive endogenous cues and targets, was implemented in a driving simulator. Participants were to follow and remember the cues to search for target pedestrians among distractors. In half of the experimental drives, additional demand on working memory was introduced by a novel math task, delivered in an auditory format, that involved subtraction, division, and assessing if the result was a whole number. In addition, incentives were provided to prioritize the pedestrian task over others. Results showed that decreasing availability of working memory deteriorated accuracy and reaction times of the pedestrian discrimination task. Prioritization was able to improve performance by reordering the concurrent tasks. We extended experimental manipulations in simple laboratory settings to dynamic environments that are representative of daily activities. Potential implications of our findings include better design of in-vehicle interfaces that do not exhaust drivers’ working memory and better driver education that emphasize the prioritization of in-vehicle tasks.
Introduction

In modern driving, more and more in-vehicle devices have become available and affordable; drivers not only control the vehicle and scan the environment but also interact with various wireless systems, such as cell phones and navigation systems. Drivers are especially vulnerable to performance decrements while performing concurrent tasks: previous studies have found evidence of impaired vehicle control (Rakauskas, Gugerty, & Ward, 2004), degraded speed and headway control (Strayer & Drews, 2004), and more misses of traffic signals (Strayer & Johnston, 2001).

Many drivers tend to offload peripheral driving tasks (i.e. speed monitoring, processing internal and external objects in the environment) in demanding situations (Beede & Kass, 2006). In some dangerous instances, priorities are incorrectly ordered and driving itself may become the peripheral activity being shed from the demands of the driver. As a result, suggested by the findings from 100-Car Naturalistic Driving study, engaging in non-driving tasks leads to higher probability of being involved in near-crashes or crashes (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006).

One explanation for degraded performance when drivers perform multiple tasks is that concurrent tasks divert drivers’ attention away from their primary driving task (Strayer & Johnston, 2001). Listening to verbal materials was not sufficient to cause interference; it was the active engagement in the concurrent tasks that interfered with the driving performance. Another possibility is that performing concurrent tasks decreases the availability of working memory that can be devoted to driving. The current study is designed to test this hypothesis. de Fockert, Rees, Frith and Lavie (2001) found that the availability of working memory for maintaining stimulus-processing priorities is critical for directing attention to relevant rather than irrelevant stimuli. Their experiments required observers to selectively attend to famous written names and ignore distracter faces while holding in working memory a sequence of digits. Observers had to remember the order of the digits and later respond to the memory probe the digit that followed this probe in the memory set. Their rationale was that observers would be more vulnerable to distracters with increasing working memory load because the increased load disrupted prioritizing attention to relevant stimuli.

Generalizing to the driving domain, our experiment used a modified Posner cue-target paradigm (Lee, Lee, & Boyle, submitted) to assess the effect of working memory availability on guidance of attention. We asked participants to drive along a rural highway and discriminate a target pedestrian among a group of similar looking pedestrians. A cue was presented to guide the search. This cue endogenously conveyed spatial prediction of the likely locations of targets, and participants had to remember the side that the cue is located on in order to more efficiently search for the targets. Participants were to maintain safe vehicle control while driving between a leading and a following vehicles. In half of the experimental drives, a secondary task involving remembering three numbers and mathematical subtraction and division was added when participants performed the pedestrian discrimination task. We hypothesized that the math
task would decrease the availability of working memory for searching of the targets. In addition, we artificially introduced prioritization of the pedestrian discrimination task by providing incentives for participants to improve their pedestrian discrimination performance. We expected that performing a secondary task would have a smaller effect on pedestrian discrimination task in the prioritized condition than in the non-prioritized condition.

**Method**

**Participants**
Sixteen native English-speaking participants performed the experiment. All participants were licensed drivers with normal or corrected-to-normal vision and normal color vision and ranged in age from 21 to 28 years (8 men and 8 women). Participants were paid $8 per hour with additional compensation (up to $8) available depending on their accuracy of the pedestrian discrimination task.

**Apparatus and Tasks**

*Driving Simulator.* Data was collected at 60 Hz with the high fidelity Beckman Institute Driving Simulator, a fixed-base, automatic transmission 1998 Saturn SL with 130° forward and rear projection screens. The driving scenarios and movement of the participant’s vehicle and interactive vehicles were simulated using DriveSafety’s Vection™ Software and their HyperDrive Authoring Suite (Version 1.6.1). Video recordings from three cameras were also collected (driver’s face, foot pedals and forward view).

*Driving Task.* The driving task required participants to drive safely between two vehicles in four drives. The environment in each drive was foggy with a straight two-lane rural road. The distance between the lead car and following car was 148 ft (45 m). The speed these two cars traveled varied between 50 and 55 mph (80 and 89 kph). There was a constant flow of ambient traffic in the left lane to prevent the participant from deviating side to side. Each drive took approximately 10 minutes to complete. Participants were asked to obey traffic laws and respond to traffic events as they normally would.

*Pedestrian Discrimination Task.* Each encounter required the participants to detect the presence of pedestrians located in driveways perpendicular to both sides of the road. A pedestrian crossing sign was presented approximately 656 ft (200 m) before each set of 5 driveways. The pedestrian crossing sign could appear on either the left or right side of the road. The side the pedestrian sign appeared on was the side of the driveway that 4 (out of 5) target pedestrians were located on. One target pedestrian would appear on the opposite side from the pedestrian sign. The scenario was programmed with enough fog to prevent the drivers from detecting the pedestrians until they were within 328 ft (100 m) of the driveways.

The pedestrians were located behind passenger cars in driveways opposite of each other (See Figure 1) (the numbers did not appear in the scenarios). The target was always
wearing a red shirt (at position 2 in Figure 1) while the others wore green shirts. Their location on the driveway was centred on the drivers’ perspective to ensure equal viewing angles of both sides (see Figure 2). Due to the presence of the fog and viewing angle of the pedestrians, the participant had less than three seconds to correctly scan each of the six locations and locate the target pedestrian as they drove by. The participants were asked to verbally report the position of the target pedestrian by saying a number 1 through 6 (labeled left to right) aloud as soon as they saw it. Each drive had 6 sets of 5 driveways, following the onset of 6 pedestrian crossing signs.

Figure 1. Driveway configuration, an aerial view

![Figure 1. Driveway configuration, an aerial view](image1)

Figure 2. Driveway configuration, from driver’s perspective (only showing positions 2 to 5)

![Figure 2. Driveway configuration, from driver’s perspective (only showing positions 2 to 5)](image2)

**In-Vehicle Math Task.** The secondary task used Gauss’ Modular Arithmetic as described in Bogomolny (2007). It consists of a math problem in the following format: “$a \equiv b \pmod{n}$” and is read: “$a$ is congruent to $b$ modulo $n$.” In the experiment, participants only heard three numbers from the car speakers, for example, 18, 7, 3. Participants were instructed to mentally subtract 7 from 18 and then divide the difference by 3. If the answer was a whole number, the statement was true; otherwise, the statement was false. The first number ranged from 11 to 20, the second number ranged from 1 to 10, and the third
number ranged from 2 to 5. All the numbers were created in a text-to-speech editor using a female voice. Participants pressed either a true or false button on the steering wheel when they finished the calculation.

Prioritization. Two drives (one involved driving and pedestrian discrimination tasks and the other involved driving, pedestrian discrimination, and math tasks) were designed to assess how prioritization affected guidance of attention. We instructed participants that they would have to improve accuracy of pedestrian discrimination in order for them and their fictitious partners to receive bonus compensation.

Experimental Design and Independent Variables
The study used a within-subjects design with the following factors: secondary task (with, without) and prioritization (yes, no). The order of the experimental conditions was semi-counterbalanced such that the first two drivers were always without prioritization conditions and the last two drivers were always with prioritization conditions.

Procedure
At the beginning of each experiment, participants were read instructions for the driving, pedestrian discrimination, and secondary tasks. A practice drive familiarized the participants with the driving dynamics of the simulator. They also learned to gauge a safe distance between the two cars in the same lane. The secondary task of performing Gauss’ Modular Arithmetic mentally was then practiced for several trials to ensure comprehension and decrease learning effects due to the uniqueness of the task. The main experimental drives began after successful completion of this practice stage.

Each experimental drive started with participants accelerating the subject vehicle and maintaining it between the lead car and the following car. When passing by a pedestrian crossing sign, participants were to remember the side of the road the pedestrian sign was located and use that information to search for the 5 targets in of the following driveways. Participants then verbally report the position number they believe the target pedestrian was. If participants drove too slowly and as a result came too close to the following vehicle, the experimenters would remind them to keep a safe distance to the lead and following cars. When the secondary task was introduced, participants would hear three numbers, do the calculation, and manually press a button on the steering wheel. The auditory messages started when pedestrians first became in sight, and participants were instructed to treat the pedestrian task as primary and the math task as secondary. Everything else being equal, emphasis was placed to improve the accuracy of the pedestrian discrimination task in two of the experimental drives. Short breaks were given after each drive. The entire experiment took about 90 min to complete. Participants were then debriefed and provided the proper amount of compensation.

Dependent Variables
In order to investigate how participants dealt with the various tasks, several driving and task related variables were measured. Only accuracy scores and reaction times for the
pedestrian discrimination task and secondary math task were reported in the current paper.

Results

The effects of secondary task and prioritization on pedestrian discrimination performance were analyzed with repeated measures ANOVAs. The statistical model was a 2 (secondary task) x 2 (prioritization) within-subjects design. The SAS mixed procedure with a compound symmetry covariance structure was used for the analysis. Cohen’s d and 95% confidence interval were also calculated to show the magnitude of the effect of the secondary task and prioritization on the dependent variables.

Pedestrian Discrimination Task

Accuracy. Having to perform a secondary task decreased the accuracy on discriminating pedestrians on driveways, $F(1, 365) = 7.53, p = .006, d = 0.27, CI = (0.07,0.23)$. The mean accuracy was 4.57 with a secondary task and was 4.72 without a secondary task. When participants were informed about improving their performance on the pedestrian discrimination task, their accuracy increased significantly, $F(1, 365) = 9.75, p = .002, d = 0.30, CI = (0.09,0.25)$. The mean accuracy was 4.56 in the no prioritization condition and was 4.73 in the prioritization condition. The interaction between secondary task and prioritization was significant, $F(1, 365) = 5.60, p = .019$, indicating that the instruction of having to improve performance did not significantly increase accuracy in the absence of a secondary task, but increased accuracy in the presence of a secondary task (Figure 3).

![Figure 3. Interaction between secondary task and prioritization on accuracy](image-url)

Reaction Time. Performing a secondary task concurrently increased reaction times on discriminating pedestrians, $F(1, 365) = 106.09, p < .0001, d = 0.84, CI = (0.64,0.90)$. The mean reaction time was 2.99 sec without a secondary task and was 3.76 sec with a secondary task. Prioritization decreased reaction times, $F(1, 365) = 53.78, p < .0001. d = 0.57, CI = (0.41, 0.68)$. The mean reaction time was 3.70 sec in the no prioritization condition and was 3.21 sec in the prioritization condition. The interaction between secondary task and prioritization was significant, $F(1,365) = 10.66, p = .001$, indicating
that prioritization significantly shortened reaction times both in the absence and in the presence of a secondary task (Figure 4), and the magnitude of improvement was greater in the absence of a secondary task.

![Figure 4. Interaction between secondary task and prioritization on reaction time](image)

**Secondary task**

**Accuracy.** Prioritization did not significantly affect the accuracy of the secondary task, $F(1,175) = 0.01, p = .909, d = 0.02, CI = (-0.12,0.14)$. The mean accuracy was 4.49 in the no prioritization condition and was 4.48 in the prioritization condition.

**Reaction Time.** Prioritization significantly decreased reaction times of the secondary task, $F(1, 175) = 38.19, p < .0001, d = 0.50, CI = (0.43,1.01)$. The mean reaction time was 2.64 sec in the no prioritization condition and was 1.92 sec in the prioritization condition.

**Discussion**

Working memory and attention are important predictors of multitasking performance (Konig, Buhner, & Murling, 2005). The current study tested the hypothesis that the availability of working memory, crucial for maintaining stimulus-processing priorities, plays a significant role in directing attention to relevant rather than irrelevant stimuli (de Fockert, Rees, Frith, & Lavie, 2001; Lavie, 2005). We tested this hypothesis by comparing drivers’ endogenous control of attention during driving only and driving while performing a secondary task that demands working memory. Our results supported the hypothesis that decreasing availability of working memory decreased endogenous control of attention. In addition, we hypothesized that if we prioritized maintaining endogenous control of attention, the demand of working memory from performing a secondary task would affect drivers less, and the results were inconclusive.

Remembering the spatial location of the endogenous cue demanded working memory. When additional demand on working memory was introduced, drivers were less accurate
and slower in responding the target locations. It is likely that by having to perform concurrent tasks, working memory became less available to maintain priorities throughout task performance. As a result, drivers were less able to utilize the endogenous cue for target searching and took a longer time to respond. Reprioritizing the pedestrian task, though artificially, improved accuracy to be equivalent to the accuracy without a secondary task. Reaction times, on the other hand, showed that reprioritizing the pedestrian task improved performance both with and without a secondary task, and the magnitude of improvement was larger for the without secondary task condition. This finding is inconsistent with our hypothesis and should be further investigated. It is possible that our instructions to prioritize one task over the other were not followed consistently: there was an improvement on speed of answering the secondary task in the prioritization condition.

Our study tested the role of working memory in maintaining priorities and the distinction between targets and distractors. We extended experimental manipulations in simple laboratory settings (Lavie & de Fockert, 2005) to dynamic environments that are representative of daily activities. Potential implications of our findings include better design of in-vehicle interfaces that do not exhaust drivers’ working memory and better driver education that emphasize the prioritization of in-vehicle tasks.
REFERENCES


