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Distracted Driving due to Visual Working Memory Load

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16. Abstract
In an attempt to understand the specific mechanism by which distractions (such as cell-phone use) can interfere with driving, this work tested the idea that driving performance depends on available space within visual short-term memory. Across trials, different amounts of available visual memory were created by the use of a concurrent visual change-detection task. The results showed the typical decrease in memory performance with higher memory loads, but no significant change in driving performance, other than an overall, non-specific, dual-task deficit. These findings suggest that driving does not depend on the fixed-capacity memory system that is assessed by standard, visual short-term memory tasks.

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Abstract

In an attempt to understand the specific mechanism by which distractions (such as cell-phone use) can interfere with driving, this work tested the idea that driving performance depends on available space within visual short-term memory. Across trials, different amounts of available visual memory were created by the use of a concurrent visual change-detection task. The results showed the typical decrease in memory performance with higher memory loads, but no significant change in driving performance, other than an overall, non-specific, dual-task deficit. These findings suggest that driving does not depend on the fixed-capacity memory system that is assessed by standard, visual short-term memory tasks.

Chapter 1 Driving Distractions and Visual Working Memory

Distracted driving is responsible for more than 5,000 deaths and nearly 500,000 injuries

per year (NHTSA, 2010). The use of a cell-phone while driving, for example, almost doubles the

odds of being in an accident (Asbridge 2013), raising the risk to equal that of being drunk

(Strayer et al. 2006), and the injuries associated with distracted driving are more severe, on

average, than those associated with other causes (Neyens and Boyle 2008). Given the dangers

posed by distracted driving, the present work was designed to test a specific mechanistic

explanation for these effects. The long-term goal is to mitigate the effects of distracted driving,

which would seem particularly important given that even people who are aware of the dangers of

distracted driving continue to do so (AAA 2012).

1.1 Visual Working Memory as the Mediator of Distracted-driver Effects

The most-popular current theory concerning the mechanism by which distractions

interfere with driving places the "blame" on visual attention (Strayer et al. 2003). According to

this view, when drivers are distracted, they are less likely to attend to important driving-related

events and are less likely to exhibit situational awareness (Kass et al. 2007). The present work

concerns an alternative view. This alternative is rooted in "load theory" (Lavie 1995) and posits

that instead of preventing attention from being focused on relevant stimuli, distractions act as

filler within the limited-capacity buffer that holds incoming visual information. This buffer –

which is referred to by various names, such as visual short-term memory (VSTM), visual

working memory, or the short-term visual store – is limited to only four or five items (Luck and

Vogel 1997). When VSTM is full, no additional items may be encoded and will be lost, even if

they are being attended. Therefore, any distraction that occupies space within VSTM will reduce

the probability that a given piece of driving-related information will be available to central

processes. Thus, via the capacity limitations of VSTM, distractions can interfere with safe driving, as well as myriad other visual tasks.

1.1.1 Scope of the Present Project

The proposed explanation for how distractions interfere with driving can best be thought of as having two steps or components: (1) distractions, such as cell-phone use or texting, occupy space within visual short-term memory, and (2) the reduction in available space within VSTM causes the loss of driving-related information. To be supported, both claims must be shown to be true, but the present project only concerns the latter. (The first claim is being tested separately.) To be clear: the present work aims to test the claim that reductions in available space within VSTM will cause measureable deficits in driving performance.

1.2 General Approach

The first difficulty in testing the idea that reductions in available VSTM space will cause deficits in driving is finding a method to collect the data safely and accurately. This will be done by using a driving simulator. The second difficulty is figuring out how to systematically vary the amount of VSTM capacity that is available for driving. This will be done by using a secondary task with various memory loads. Given that the typical capacity of VSTM is four or five items, several of the loads imposed by the secondary task will be four items or less, which should allow the driving task to continue with minimal interference, while one load will be greater than the capacity of VSTM, which should cause large amounts of driving error.

It should be noted in advance that a difference in driving performance between a no-load control and the lowest load level of one item would not constitute evidence in favor of the current hypothesis. This holds because any load above zero implies a secondary task, while zero load is the same as no second task. Finding a measureable dual-task cost of any sort doesn't

necessarily implicate VSTM, as many other control mechanisms are required when two tasks must be done concurrently. There needs to be a reliable difference between the low- and high-load conditions.

Chapter 2 Experiment

The purpose of this experiment was to acquire measures of driving performance under a variety of concurrent visual working memory loads. Participants were instructed to "follow the red pick-up truck" while also performing a visual memory task once every two minutes – namely, change detection between prime and probe. The number of items to be held in VSTM varied from one to eight across trials. The retention interval was extended compared to previous work in order to collect sufficient data while VSTM was occupied.

2.1 Methods

2.1.1 Participants

A total of 19 university undergraduates, 11 females and 8 males with a mean age of 19.2 years, participated in the study in return for partial course credit. The data from three participants were discarded: two for failing to obey instructions and one for being at chance on the memory task.

2.1.2 Driving Task

The driving task employed a NADS MiniSim™ (with front display only, to reduce the chances of VR sickness) and required participants to follow a lead vehicle on a straight road. The lead vehicle's speed varied between 50 and 60 mph (on a sine function with a period of three minutes). The simulated driven vehicle was a recent Chevrolet Malibu with an automatic transmission. A large number of variables were recorded, including all control inputs, vehicle speed, lane position, and most importantly, following distance.

2.1.3 Visual Working Memory Task

The concurrent VSTM task was a modified version of that developed by Luck and Vogel (1997). Each trial began with a medium-pitch tone that served as a warning to participants,

followed by the prime display for 500 milliseconds. Prime displays included one, two, four, or eight colored shapes. After a retention interval of 15 seconds, a high-pitched tone was followed by a probe display for 750 milliseconds. For half of the trials, the probe was the same as the prime; for the other half of the trials, the color or shape of one item in the probe display was different from what it had been in the prime. Participants made a vocal "same" or "different" response, which was entered by key-press by the researcher.

2.1.4 Procedure

After providing informed consent, participants practiced driving the simulated vehicle for five minutes. They then practiced the VSTM, with the car parked, for ten trials. Finally, they began to follow the lead vehicle and were given VSTM trials at a rate of one every two minutes. The final phase continued until five trials in each of the four memory-load conditions had been completed, which required slightly more than 40 minutes. Participants were then debriefed and any questions were answered.

2.1.5 Data Reduction

The driving data were first parsed into five different categories: between VSTM trials (hereafter: the load = 0 condition), during load = 1 trials, during load = 2 trials, during load = 4 trials, and during load = 8 trials. The zero-load data were then greatly reduced by retaining a random set of 15-second segments to match the amount of data in each of the other conditions. Next, using only the middle 10 seconds of each retention interval, the standard deviation of the following distance was calculated. The vocal responses from the VSTM task were also coded for accuracy.

2.2 Results

Before turning to the analysis of following distance (variability), the expected and often-replicated effect of memory load on visual change-detection accuracy was verified. As can be seen in table 2.1 and as shown by ANOVA, memory performance did decrease with increasing memory load: $F(3,45) = 112.96$, $p < .001$. Overall accuracy was lower than is typically observed (Luck & Vogel 1997), but this is not surprising, given the concurrent driving task and the abnormally long retention interval employed.

Table 2.1 Performance on the memory task

Load	mean Proportion Correct
1	0.73 ± 0.03
2	0.70 ± 0.03
4	0.64 ± 0.03
8	0.55 ± 0.03
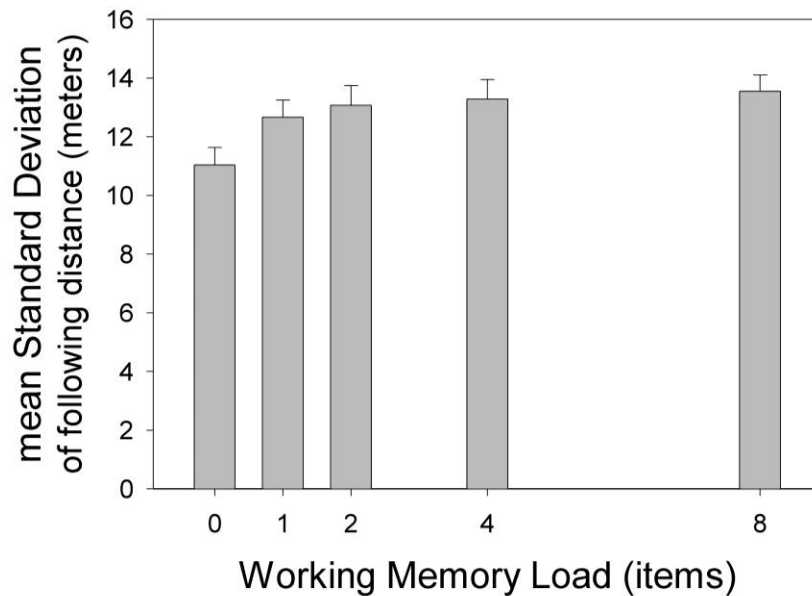
Figure 2.1 Variability in following distance as a function of memory load

The first analysis of driving performance (i.e., the variability of following distance) included all five conditions: no memory load, load = 1, load = 2, load = 4, and load = 8. In this case, the preliminary test for a violation of the sphericity assumption was significant (Mauchly's $W = 0.139$, df = 9, $p = .002$), so the Huynh-Feldt correction was applied. The main effect of load condition was significant: $F(3.32, 48.15) = 15.26$, $p < .001$. As can be seen in figure 2.1 and as verified by follow-up tests, the zero-load condition differed from all others: $F(1,15) = 477.65$, $p < .001$ (for the planned zero-load vs all others contrast). The apparent quadratic trend was also reliable: $F(1,15) = 10.53$, $p = .005$. However, when tested separately from zero load, the four conditions with non-zero memory loads did not differ from each other: $F(3,45) = 1.64$, $p = .193$.

2.3 Discussion

Taken at face value, the present results appear to provide clear evidence against the idea that driving performance, at least as indexed by the variability in following distance, depends on the amount of currently-available visual working memory (VSTM). While an overall deficit in driving performance was observed when participants were holding items in VSTM as opposed to driving with nothing in memory (i.e., load > 0 vs load = 0), the magnitude of this deficit did not depend on the number of items being held. The overall deficit provides no support for the original hypothesis, as this difference is confounded by one vs multiple tasks and, therefore, might have little or nothing to do with VSTM.

One possible explanation for the lack of a load-size effect on driving performance is that participants did not attempt to maintain a consistent following distance or otherwise drive safely while holding items in visual working memory. Expressed another way, participants may have treated the entire experiment as two, alternating single tasks, consistent with how the tasks were introduced at the start of the session, as opposed to a dual task. This would make the present

results non-diagnostic, since the VSTM task here was being used to create different conditions for assessing driving, so the two tasks needed to be performed at once.

To address this possibility, the association between driving and memory performance was measured by correlation. The alternating single-tasks explanation predicts no relationship, as the two tasks are posited to not co-occur. In contrast, the assumed dual-task account predicts a significant relationship as attention and other resources are traded off between the simultaneous driving and memory tasks. A very strong relationship was observed, $r = .74$, $p < .001$ (i.e., higher memory scores co-occurred with larger standard deviations in following distance), ruling out the alternative and supporting the *prima facie* interpretation. Thus, as of now, the present data must be taken as evidence against the idea that driving depends on the same, numerically-limited resource as VSTM tasks.

Chapter 3 Implications and Future Directions

The primary implication of this work is that the proposed alternative to the currently dominant explanation of the effects of distraction on driving enjoys no support. Thus, it makes more sense to continue to explore the role of attention in distracted driving than the role of visual short-term memory (VSTM).

With that said, the present findings do not constitute a definitive disproof of the VSTM model. Most of all, the results from the memory task showed relatively low levels of accuracy, suggesting that participants did not prioritize this task highly. In fact, at the larger display sizes, performance was barely above chance. This leaves the possibility open that participants were not storing all of the items, such that VSTM capacity was not being used up or filled in the intended manner. If this were the case, then the present study would not provide strong evidence against the VSTM model, as the available space within VSTM was not being manipulated as planned. In subsequent work, some method of verifying the amount of free capacity within VSTM should be included. Unfortunately, no such method yet exists within the literature; it must be developed.

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Appendix A Extra Information

Two points are worth mentioning for those who might wish to replicate or extend this work. First, when combining a secondary task with driving, some form of warning before each secondary-task trial is critical. In the present experiment, a brief tone was used. Without the warning, as was done in some pilot work, participants would repeatedly check the secondary display and driving would suffer in the control conditions.

Second, the secondary task should employ a vocal response. In one pilot version of the present experiment, the "paddles" on the Logitek wheel were used for responses, but most participants made unintended steering changes when making responses. If a voice-recognition system is available it should be used, otherwise, a research assistant should enter the vocal responses.