

Telephone conversation impairs sustained visual attention via a central bottleneck

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Recent research has shown that holding telephone conversations disrupts one's driving ability. We asked whether this effect could be attributed to a visual attention impairment. In Experiment 1, participants conversed on a telephone or listened to a narrative while engaged in multiple object tracking (MOT), a task requiring sustained visual attention. We found that MOT was disrupted in the telephone conversation condition, relative to single-task MOT performance, but that listening to a narrative had no effect. In Experiment 2, we asked which component of conversation might be interfering with MOT performance. We replicated the conversation and single-task conditions of Experiment 1 and added two conditions in which participants heard a sequence of words over a telephone. In the shadowing condition, participants simply repeated each word in the sequence. In the generation condition, participants were asked to generate a new word based on each word in the sequence. Word generation interfered with MOT performance, but shadowing did not. The data indicate that telephone conversation disrupts attention at a central stage, the act of generating verbal stimuli, rather than at a peripheral stage, such as listening or speaking.

How does distraction affect cognitive performance? In everyday life, we repeatedly perform multiple tasks simultaneously. We often walk down a street talking to a friend or search for our keys while listening to the radio, and, in some instances, we have cell phone conversations while we drive cars.

Phenomena associated with the performance of multiple tasks have been the subject of recent scrutiny in the laboratory. Dual-task deficits (i.e., performance costs when two tasks are performed together rather than separately) are well known in the literature (e.g., Allen, McGeorge, Pearson, & Milne, 2006; Allport, Antonis, & Reynolds, 1972; Fougne & Marois, 2006; Pashler & O'Brien, 1993). A prominent and socially relevant set of studies has extended this paradigm to the study of a commonplace, voluntary dual-task situation: driving while talking on a mobile phone (Briem & Hedman, 1995; Strayer & Drews, 2007; Strayer, Drews, & Crouch, 2006; Strayer & Johnston, 2001). For example, Strayer et al. (2006) compared the performance of drunk drivers with that of drivers talking on a phone. Although the patterns of behavior of the

two groups differed (e.g., drunk drivers exhibited more aggressive behavior by driving closer to vehicles in front and braking harder, whereas drivers conversing on a cell phone showed delayed braking responses), both groups showed severe impairments in driving performance. Although it may come as no surprise that alcohol impairs driving performance, the worrying finding was that participants talking on a mobile phone were also involved in more accidents than when they were not.

What underlies these effects of distraction? The central concept invoked is *selective attention*, our ability to focus limited processing resources on certain stimuli while ignoring others. Why does talking on a mobile phone disrupt a person's driving ability? Strayer and Johnston (2001) suggested that telephone conversations reduce the amount of attention that can be devoted to the driving task, thus impairing performance. This is inferred from the fact that peripheral factors, such as motor interference from holding the phone, can be ruled out: Drivers were equally impaired, regardless of whether they were using a hands-free or handheld device (Strayer et al., 2006; Strayer &

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Johnston, 2001). Furthermore, Strayer and Drews (2007) investigated participants' memory for objects they had fixated while performing a simulated driving task under two conditions: talking and not talking on a mobile phone. In a surprise memory test after the experiment, it was found that talking on the phone reduced recognition performance by 50%, relative to the driving-alone condition. Furthermore, recall for items that participants had directly fixated was also impaired.

From these data, Strayer and Drews (2007) argued that phone conversation leads to inattentive blindness (Mack & Rock, 1998). Additional support for this hypothesis came from a separate experiment in which Strayer and Drews measured event-related potentials (ERPs) elicited during driving with or without a phone conversation. They found that the amplitude of the P300 component was smaller in the conversation condition than in the control condition. Because the P300 is assumed to reflect the allocation of attention to a task (Sirevaag, Kramer, Coles, & Donchin, 1989), this result suggests that telephone conversation disrupted attention during driving.

However, although attentional impairments are one route to disrupted memory, we cannot conclusively infer attentional impairment from reduced memory performance. For example, it could also be argued that the act of talking on a mobile phone, rather than attention per se, interfered with updating working memory for later recall; P300 amplitude is also thought to reflect updating of working memory (e.g., Donchin & Coles, 1988). Because the effect of telephone conversation on visual attention has not been tested directly, it is still unclear whether the deficit observed in driving when talking on a phone reflects a disruption of attention or something else (such as a disruption in updating memory).

Our goal was to test directly whether telephone conversation disrupts attention. We investigated this using the multiple object tracking (MOT) paradigm (Pylyshyn & Storm, 1988). In MOT, participants are shown an array of identical objects, a subset of which are designated as targets. The task is to track the targets among the independently moving objects for a period of from several seconds to several minutes (Wolfe, Place, & Horowitz, 2007). The standard result is that participants can track around 3–5 targets (Cavanagh & Alvarez, 2005). For our purposes, the advantage of the MOT procedure is that it taps into both selective and sustained aspects of attention, without engaging complex motor or task-switching components. In essence, MOT is a good measure of how well participants can sustain visual attention over time (e.g., Horowitz et al., 2007). In order to successfully complete the tracking task, participants have to continually attend to all targets. Without this sustained attention, participants are unable to distinguish targets from distractors.

As we note above, it is now well established that telephone conversation impairs driving, and it is intuitively obvious that driving requires attention. However, the act of driving comprises several tasks that participants have to engage in concurrently to safely navigate a vehicle. For example, while remaining visually aware of their environ-

ment (the attentional factor), drivers must perform other tasks, such as responding manually to the curvature of the road (by adjusting the steering wheel), updating information from side- and rearview mirrors, and controlling the speed of the car by using the brake and accelerator pedals. Telephone conversation might hurt driving by interfering with any of these subtasks individually or with the ability to switch attention among them. If phone conversation reduces MOT performance, we can claim confidently that telephone conversation impairs visual attention. However, if the MOT paradigm is immune to such interference, the problem may be of a purely central executive nature.

In Experiment 1, we compared the dual-task deficit in MOT performance while participants engaged in a telephone conversation (Experiment 1A) with the dual-task deficit induced by listening to a narrative (Experiment 1B). We found that the conversations interfered with MOT, whereas the control listening task did not.

The narrative condition of Experiment 1 demonstrated that listening did not impair tracking. In Experiment 2, we asked whether it was the motor act of producing speech that interfered with MOT, or whether the bottleneck was at the more central stage of speech generation in response to either a specific conversational context or set of instructions. In this experiment, we looked at the effect of *shadowing speech* (repeating back words to the experimenter) on MOT performance versus having to generate a new word based on a set of word-game rules. We found that shadowing speech did not impair MOT performance, but that having to generate new words did. Thus, the interference of conversing during an attentional task is not a low-level motor interference, but is a more global impairment in cognitive processes needed for sensible and meaningful conversation. Put together, these data have implications as to why telephone conversations impair driving.

METHOD

Participants

All participants were recruited from the volunteer panel of the Brigham and Women's Hospital Visual Attention Laboratory. Each participant passed the Ishihara test for color blindness and had normal or corrected-to-normal vision. All participants gave informed consent, as approved by the Partners HealthCare Corporation IRB, and were compensated \$10/h for their time.

Each experiment (1A, 1B, and 2) involved 12 participants.

Stimuli and Procedure

Each experiment consisted of a *single-task* condition, in which participants performed the MOT task without any other demands, and one or more *dual-task* conditions.

MOT. The MOT procedure was identical for all three experiments. The tasks were conducted on a Macintosh computer running OS 9.2, controlled by MATLAB 5.2.2 and the Psychophysics Toolbox Version 2 (Brainard, 1997; Pelli, 1997). The stimuli were eight dark gray disks subtending 1.5° of visual angle at a viewing distance of 57 cm against a uniform light gray background.

Participants were instructed to track four target disks. At the beginning of each trial, the target disks briefly flashed yellow before returning to their original color, at which point all eight disks began to move. Initially, disks were assigned a random velocity vector, and then followed a repulsion algorithm that ensured that the disks never occluded one another. The algorithm resulted in unpredictable,

random trajectories. Disk speed averaged 6.7°/sec, with a standard deviation of 3.2°/sec. After 3.0 sec, one of the eight disks turned red. Participants were asked to respond to whether the red disk was a target by pressing one of two keys: the “a” key or the quote (”) key. Participants were asked to respond as quickly and accurately as possible.

Dual tasks. Experiment 1A had one dual-task condition, *telephone conversation*, in which participants engaged in a telephone conversation with an experimenter who sat in a separate room during the MOT task. The conversations were meant to be as naturalistic as possible, so there was no explicit template. Conversation topics included, but were not limited to, such topics as hobbies and what people did on their weekends or vacations. The main stipulation for each conversation, however, was that both the participant and the experimenter made approximately equal contributions. All conversations were conducted over speakerphone (i.e., hands free) so that any performance deficit could not be attributed to motor interference. Following the experiment, participants were asked whether they ever held cell phone conversations while driving.

Experiment 1B employed the *narrative* dual-task condition. Participants listened to a recording of part of the novel *Dracula* by Bram Stoker while completing the MOT task. The narrative was taken from chapter 1, which is less well known than later chapters so that participants were unlikely to be familiar with it. To ensure that participants listened actively, they were told to pay attention to the passage and that they would be asked questions about it after they completed the condition. Participants listened to the story over headsets while performing the MOT task.

Experiment 2 included three dual-task conditions: *telephone conversation*, *shadowing*, and *generation* (cf. Strayer & Johnston, 2001). The telephone conversation condition was the same as in Experiment 1A. In the shadowing condition, instead of engaging in conversation, the experimenter slowly recited a list of words over the telephone, and participants had to repeat each word (e.g., if the experimenter said “green,” the participant also said “green”). The *generation* condition was similar to the shadowing condition, except that, instead of repeating the word, participants had to generate a new word starting with the last letter of the stimulus word (e.g., if the experimenter said “green,” the participant had to generate a word that began with the letter “n”). In both conditions, the presented words came from a list of four- and five-letter words spoken at a rate of one word approximately every 4 sec. The words on the list were shuffled randomly for each participant. In all experiments, conditions were counterbalanced across participants, and each condition consisted of 5 practice trials followed by 50 experimental trials. In Experiment 2 (but not in Experiment 1), all conditions were recorded digitally with Audacity 1.2.5 software (audacity.sourceforge.net).

Data Analysis

We analyzed reaction times (RTs) and accuracy. RTs less than 200 msec or greater than 4,000 msec were removed as outliers. This led to the removal of less than 1% of the data for Experiment 1A, no data for Experiment 1B, and 1.4% of the data for Experiment 2. Accuracy data were transformed into the signal detection sensitivity parameter d' ; 0.5 errors were added to cells with no errors (Macmillan & Creelman, 2005). Error bars on all figures denote within-subjects 95% confidence intervals (Loftus & Masson, 1994).

In Experiment 1A, there were no differences in RTs or accuracy between the 3 participants who said that they regularly spoke on a mobile phone when driving and the 9 who said that they did not. Thus, the data were collapsed across this variable.

In Experiment 1B, 8 of the 12 participants answered all the questions about the story correctly. The other 4 each made only one mistake. We therefore assumed that all participants were listening actively to and comprehending the story. In Experiment 1A, we assumed that the participants and the experimenter made equal contributions to the conversation. In Experiment 2, we verified this assumption by analyzing the audio recordings, which showed that

participants spoke on average for 50% of the time, and the experimenter spoke for 49% of the time (the remaining time was taken up by nonverbal noise, such as laughter). Accuracy in the shadowing and generation tasks was also high (participants showed 92%, $SE \pm 2\%$, and 89%, $SE \pm 2\%$, correct, respectively). Thus, it is clear that in all dual-task conditions, participants were performing the concurrent auditory-verbal task to an acceptable standard.

RESULTS

Figures 1 and 2 summarize the data from all three experiments in terms of speed-accuracy plots. RT is shown on the abscissa and d' on the ordinate. Thus, good performance is up and to the left, and bad performance is down and to the right. Figure 1 (showing data from Experiments 1A and 1B) contrasts the effects of telephone conversation and listening. The data clearly fall into two clusters. In the upper left (good performance), we find the two single-task conditions and the narrative condition. Speed and accuracy in the narrative condition did not differ statistically from the corresponding single-task baseline (all $t_s < 1$, n.s.). The telephone condition stands out on this figure, situated down and to the right of the other conditions. Performance in this condition was slower [$t(11) = -2.5$, $p < .05$] and accuracy was poorer [$t(11) = 2.5$, $p < .05$] than in its single-task baseline, demonstrating a dual-task deficit. The telephone conversation interfered

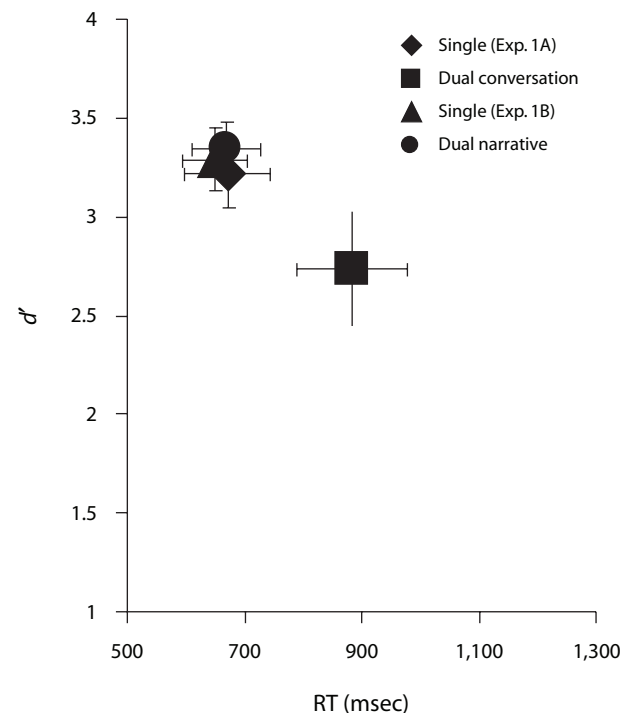


Figure 1. Speed-accuracy plot of Experiment 1. Reaction times (RTs) are plotted on the x-axis, and d' is plotted on the y-axis. Good performance is therefore up and to the left, and poor performance is down and to the right. All error bars denote within-subjects 95% confidence intervals (Loftus & Masson, 1994).

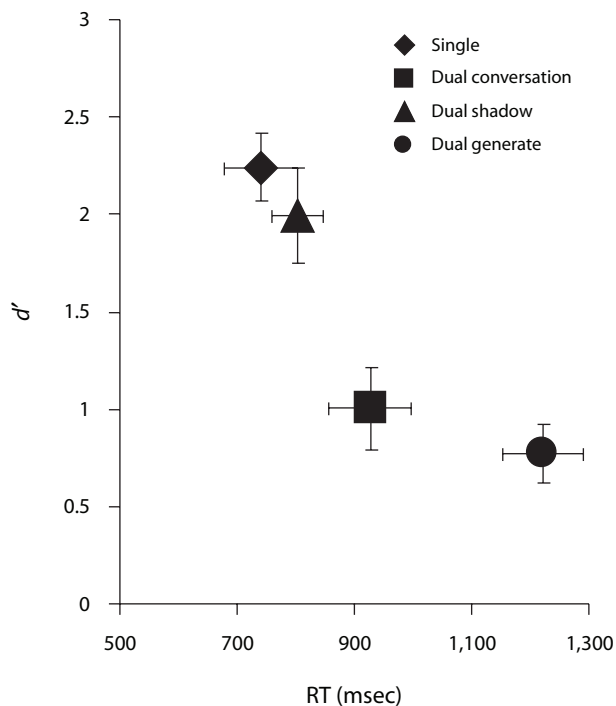


Figure 2. Speed–accuracy plot of Experiment 2. Reaction times (RTs) are plotted on the *x*-axis, and *d*' is plotted on the *y*-axis. Good performance is therefore up and to the left, and poor performance is down and to the right. All error bars denote 95% within-subjects confidence intervals (Loftus & Masson, 1994).

substantially with MOT performance in a way that listening actively to an engaging story did not.

Experiment 2 indicates why telephone conversations interfere with tracking. The data, shown in Figure 2, are very clearly ordered. In the upper left (good performance), we find the single-task and shadowing condition. Moving down and to the right (impaired performance), we find the telephone conversation and generation condition. Simply repeating back a word in the shadowing condition did not produce any dual-task interference. Performance here did not differ statistically from that of the single-task condition in either speed [$t(11) = -1.5$, n.s.] or accuracy [$t(11) = 1.2$, n.s.]. However, having a conversation or generating a new word did impair MOT performance. Participants were slower and less accurate, both in the telephone conversation condition [RT, $t(11) = -2.9$, $p < .05$; accuracy, $t(11) = 6.8$, $p < .01$] and in the generation condition [RT, $t(11) = -7.3$, $p < .05$; accuracy, $t(11) = 6.3$, $p < .01$] as compared with the single-task condition. It seems that the bottleneck in dual-task interference in these tasks lies in the cognitive realm of generating new words rather than in the motor act of producing speech.

MOT accuracy in the telephone conversation condition was identical to that of the generation condition [$t(11) = 1.2$, n.s.]. However, participants were slower in the generation condition than in the telephone conversation condition [$t(11) = -4.5$, $p < .01$]. There may be two reasons for this. If generation is more difficult than conversation, it would require more resources, and fewer were avail-

able for the MOT task. Alternatively, participants may be simply more familiar with conversation than with the novel generation tasks; well-practiced tasks require fewer resources (e.g., Allport et al., 1972; Shaffer, 1975). Nevertheless, the important finding is that *both* of these conditions (even the “well-practiced” conversation condition) were impaired severely when compared with conditions in which participants performed only the MOT task.

DISCUSSION

Our goal was to determine whether telephone conversation could impair performance on a sustained visual attention task. The literature clearly indicates that telephone conversations impair performance on simulated driving tasks (Strayer et al., 2006). However, driving is a complex task, or rather a set of tasks, requiring not only visual attention but also visuomotor coordination and high-level executive functioning. Previous studies have *implicated* visual attention by showing impaired recognition of previously seen objects (Strayer & Drews, 2007), memory (Strayer & Drews, 2007; Strayer, Drews, & Johnston, 2003), and change detection (McCarley et al., 2004). However, our data demonstrate directly that telephone conversation impairs performance on a sustained visual attention task (i.e., MOT). MOT is an excellent test of sustained visual attention, because participants need to continually attend to and track the relevant targets in order to have any hope of successfully completing the task. As in simulated driving studies (McCarley et al., 2004; Strayer & Johnston, 2001), neither shadowing nor listening to an engaging narrative imposed costs on MOT performance. However, conversation and word generation, both of which have an additional cognitive component, did impede MOT performance. It is likely that it is this cognitive, generative speech component that interferes with driving when conversing on a telephone (see also Strayer & Johnston, 2001).

The effects we report in these experiments are important from both practical and theoretical standpoints. Consider the data in Figure 1. Telephone conversation slowed RTs by 212 msec, relative to the single-task condition. If we assume that this result would generalize to driving, talking on a mobile phone would lead a driver going 60 mph to travel an additional 18.5 ft (more than the length of the average car) before braking. The effect of listening to the radio, or to an audiobook, would be about 1.8 ft (and remember that responses were slightly more accurate in the narrative condition).

Theoretically, these data can also be taken as support for cross-modal links between visual and auditory attention (Spence & Read, 2003). There is evidence of a deep linkage between the brain systems that orient visual attention and those that orient auditory attention (Ward, McDonald, & Golestani, 1998). It is known that auditory dual tasks can interfere with encoding and recall for visual stimuli (Dell'Acqua & Jolicœur, 2000; Herdman & Friedman, 1985; Jolicœur, 1999). Evidence for a central, or amodal, pool of attentional resources has come from a variety of cross-modal paradigms, including discrete visual tasks and both discrete and continuous auditory tasks

(for a review, see Arnell, 2001). What is new here is a demonstration of interference between a continuous auditory task and a continuous visual task.

Our interpretation of these data is that MOT draws both on purely visual attention resources and on central, or amodal, attention resources. Generating verbal content competes for the amodal resources, leading to interference between MOT (or driving, presumably) and conversation. It might be misleading to describe telephone conversation as an *auditory* task in this context, because simple listening does not cause problems (Experiment 1B); only when participants must cognitively generate speech do we observe interference (Experiments 1A and 2).

This finding of interference between auditory-verbal tasks and a visual attention task poses a challenge for multiple resource models of dual-task performance (Navon & Gopher, 1979; Wickens, 1984). For example, Wickens's (1984) multiple-resource theory hypothesized that a larger dual-task cost is associated with tasks that share common components than with those that do not. More specifically, the theory predicts a higher dual-task cost between two tasks that share a modality (e.g., two visual tasks) than between two tasks presented in separate modalities (e.g., a visual and an auditory task; Wickens, Sandry, & Vidulich, 1983). However, we found a large dual-task cost even though the tracking and conversation tasks occurred in different modalities. Wickens (2002) argued that similar findings from Strayer and Johnston (2001) could be accommodated by assuming that some tasks are simply so "engaging" that the competing task is dropped altogether (see also Helleberg & Wickens, 2003). Although such an explanation might be plausible for conversation as a secondary task, the fact that we obtained similar findings using a word-generation task indicates that our data might be more parsimoniously explained via an amodal, central bottleneck.

Our data clearly indicate that the bottleneck in question lies at a central, cognitive stage of processing. Only the more complex, cognitive tasks of word generation interfere with MOT, as opposed to the more purely motor task of repeating speech. There may also be other bottlenecks that appear at earlier motor stages in these types of tasks. Levy, Pashler, and Boer (2006) found that, in a driving simulation task, participants were slower to brake if they had recently responded either vocally or manually to a visual or auditory stimulus. The data suggested that both of these response types are subject to the psychological refractory period effect, where response to a second stimulus is slowed the closer in time it is to a primary task (see Pashler & Johnston, 1998, for a review). Although in this study, we found that our bottleneck occurred at a slightly later stage than that of Levy et al.,¹ our data concur with their general conclusion that the bottleneck observed in these tasks is "central" in nature. Regardless of differences in sensory or response modalities and processing stages, there is a common mental resource such that, if two such tasks are performed in parallel, performance on at least one task suffers.

Another point to note is that talking on a telephone may have a social element that listening to a recorded narra-

tive does not. Participants may feel more social pressure to maintain a conversation than they would to listen to an auditory message.² This could make the conversation task more difficult than the narrative task in Experiment 1, requiring more cognitive resources and leaving fewer to spend on the attentional task. In Experiment 2, all of the tasks involved a social interaction between the participant and the experimenter. One might hypothesize that conversation imposes unique social pressures that shadowing, even over the telephone, does not. In that case, however, it is difficult to explain why word generation was even more difficult than conversation. Nevertheless, it is important to keep in mind the social aspect of telephone conversation in the real world. Please note that our participants might not be as invested in their conversations with the experimenter as they are when talking to friends, family, or business associates. Thus our laboratory studies may underestimate the danger posed by mobile phone conversations while driving in the real world.

Telephone conversations probably disrupt driving via multiple pathways. Our data clearly implicate attention, but we can also infer a problem at the level of executive control. Previous work (Alvarez, Horowitz, Arsenio, DiMase, & Wolfe, 2005) has demonstrated that there is minimal interference between visual search and MOT, a finding that they have attributed to time-sharing between the two demanding visual attention tasks. Why does time-sharing fail in our paradigm? As Strayer and Drews (2007) have noted, conversation occurs in natural segments ("turns") that cannot be broken up arbitrarily. Thus, the tracker (or driver) cannot shift attention between the two tasks at will, or according to the difficulty of the MOT task at the moment (cf. Grabowecky, Iordanescu, & Suzuki, 2007), but is at the mercy of an interlocutor. For this reason, conversations with passengers are generally less dangerous than are mobile phone conversations, because passengers may also be attending to the difficulty of the driving task and can modulate their conversation accordingly.

In summation, this article underscores the known dangers of talking on a telephone while driving. New to the literature is the fact that telephone conversations impair sustained visual attention. When impairment of sustained visual attention is put together with both the concept of a central bottleneck and the extra burden on executive control, it is clear that both drivers and driving regulators should take the implications of such actions seriously.

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REFERENCES

- ALLEN, R., McGEORGE, P., PEARSON, D. G., & MILNE, A. (2006). Multiple-target tracking: A role for working memory? *Quarterly Journal of Experimental Psychology*, *59*, 1101-1116.

- ALLPORT, D. A., ANTONIS, B., & REYNOLDS, P. (1972). On the division of attention: A disproof of the single channel hypothesis. *Quarterly Journal of Experimental Psychology*, **24**, 225-235.
- ALVAREZ, G. A., HOROWITZ, T. S., ARSENIO, H. C., DiMASE, J. S., & WOLFE, J. M. (2005). Do multielement visual tracking and visual search draw continuously on the same visual attention resources? *Journal of Experimental Psychology: Human Perception & Performance*, **31**, 643-667.
- ARNELL, K. M. (2001). Cross-modal interactions in dual-task paradigms. In K. Shapiro (Ed.), *The limits of attention: Temporal constraints in human information processing* (pp. 141-177). Oxford: Oxford University Press.
- BRAINARD, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision*, **10**, 433-436.
- BRIEM, V., & HEDMAN, L. R. (1995). Behavioural effects of mobile telephone use during simulated driving. *Ergonomics*, **38**, 2536-2562.
- CAVANAGH, P., & ALVAREZ, G. A. (2005). Tracking multiple targets with multifocal attention. *Trends in Cognitive Sciences*, **9**, 349-354.
- DELL'ACQUA, R., & JOLICŒUR, P. (2000). Visual encoding of patterns is subject to dual-task interference. *Memory & Cognition*, **28**, 184-191.
- DONCHIN, E., & COLES, M. G. H. (1988). Is the P300 component a manifestation of context updating? *Behavioral & Brain Sciences*, **11**, 357-374.
- FOUGNIE, D., & MAROIS, R. (2006). Distinct capacity limits for attention and working memory: Evidence from attentive tracking and visual working memory paradigms. *Psychological Science*, **17**, 526-534.
- GRABOWECKY, M., IORDANESCU, L., & SUZUKI, S. (2007). Attentive tracking involves a demand-based dynamic redistribution of attention [Abstract]. *Journal of Vision*, **7**(9), 580a.
- HELLEBERG, J. R., & WICKENS, C. D. (2003). Effects of data-link modality and display redundancy on pilot performance: An attentional perspective. *International Journal of Aviation Psychology*, **13**, 189-210.
- HERDMAN, C. M., & FRIEDMAN, A. (1985). Multiple resources in divided attention: A cross-modal test of the independence of hemispheric resources. *Journal of Experimental Psychology: Human Perception & Performance*, **11**, 40-49.
- HOROWITZ, T. S., KLIEMER, S. B., FENCSEK, D. E., YANG, K. K., ALVAREZ, G. A., & WOLFE, J. M. (2007). Tracking unique objects. *Perception & Psychophysics*, **69**, 172-184.
- JOLICŒUR, P. (1999). Dual-task interference and visual encoding. *Journal of Experimental Psychology: Human Perception & Performance*, **25**, 596-616.
- LEVY, J., PASHLER, H., & BOER, E. (2006). Central interference in driving: Is there any stopping the psychological refractory period? *Psychological Science*, **17**, 228-235.
- LOFTUS, G. R., & MASSON, M. E. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin & Review*, **1**, 476-490.
- MACK, A., & ROCK, I. (1998). *Inattention blindness*. Cambridge, MA: MIT Press.
- MACMILLAN, N. A., & CREELMAN, C. D. (2005). *Detection theory: A user's guide* (2nd ed.). Mahwah, NJ: Erlbaum.
- MCCARLEY, J. S., VAIS, M. J., PRINGLE, H., KRAMER, A. F., IRWIN, D. E., & STRAYER, D. L. (2004). Conversation disrupts change detection in complex traffic scenes. *Human Factors*, **46**, 424-436.
- NAVON, D., & GOPHER, D. (1979). On the economy of the human-processing system. *Psychological Review*, **86**, 214-255.
- PASHLER, H., & JOHNSTON, J. C. (1998). Attentional limitations in dual-task performance. In H. Pashler (Ed.), *Attention* (pp. 155-189). Hove, U.K.: Psychology Press.
- PASHLER, H., & O'BRIEN, S. (1993). Dual-task interference and the cerebral hemispheres. *Journal of Experimental Psychology: Human Perception & Performance*, **19**, 315-330.
- PELLI, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision*, **10**, 437-442.
- PYLYSHYN, Z. W., & STORM, R. W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism. *Spatial Vision*, **3**, 179-197.
- SHAFFER, L. H. (1975). Multiple attention in continuous verbal tasks. In P. M. A. Rabbitt & S. Dornic (Eds.), *Attention and performance V* (pp. 157-167). New York: Academic Press.
- SIREVAAG, E. J., KRAMER, A. F., COLES, M. G. H., & DONCHIN, E. (1989). Resource reciprocity: An event-related brain potentials analysis. *Acta Psychologica*, **70**, 77-97.
- SPENCE, C., & READ, L. (2003). Speech shadowing while driving: On the difficulty of splitting attention between eye and ear. *Psychological Science*, **14**, 251-256.
- STRAYER, D. L., & DREWS, F. A. (2007). Cell-phone-induced driver distraction. *Current Directions in Psychological Science*, **16**, 128-131.
- STRAYER, D. L., DREWS, F. A., & CROUCH, D. J. (2006). A comparison of the cell phone driver and the drunk driver. *Human Factors*, **48**, 381-391.
- STRAYER, D. L., DREWS, F. A., & JOHNSTON, W. A. (2003). Cell phone-induced failures of visual attention during simulated driving. *Journal of Experimental Psychology: Applied*, **9**, 23-32.
- STRAYER, D. L., & JOHNSTON, W. A. (2001). Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular telephone. *Psychological Science*, **12**, 462-466.
- WARD, L. M., McDONALD, J. J., & GOLESTANI, N. (1998). Cross-modal control of attention shifts. In R. D. Wright (Ed.), *Visual attention* (pp. 232-268). New York: Oxford University Press.
- WICKENS, C. D. (1984). Processing resources in attention. In R. Parasuraman & D. R. Davies (Eds.), *Varieties of attention* (pp. 63-102). Orlando, FL: Academic Press.
- WICKENS, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science*, **3**, 159-177.
- WICKENS, C. D., SANDRY, D. L., & VIDULICH, M. (1983). Compatibility and resource competition between modalities of input, central processing, and output. *Human Factors*, **25**, 227-248.
- WOLFE, J. M., PLACE, S. S., & HOROWITZ, T. S. (2007). Multiple object juggling: Changing what is tracked during extended multiple object tracking. *Psychonomic Bulletin & Review*, **14**, 344-349.

NOTES

1. Presumably this was a result of the different experimental demands.
2. We thank an anonymous reviewer for this suggestion.

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