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Telephone Conversation Impairs Sustained Visual Attention Via A Central Bottleneck

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Abstract

Recent research has shown that telephone conversations disrupt 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, while 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. We added two conditions in which participants heard a sequence of words over the 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, while 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.

Introduction

How does distraction affect cognitive performance? In every day life we are repeatedly performing multiple tasks simultaneously. We often walk down a street talking to a friend, search for our keys while listening to the radio and in some instances drive cars while talking on a mobile telephone.

These phenomena have been the subject of recent scrutiny in the laboratory. Dual task deficits (i.e. performance costs when participants perform two tasks together compared to when they perform the two tasks separately) are well-known in the literature (e.g. Allen, McGeorge, Pearson, & Milne, 2006; Allport, Antonis, & Reynolds, 1972; Fougnie & Marois, 2006; Pashler & O'Brien, 1993). A prominent and socially relevant set of studies has extended this paradigm to the study of a popular voluntary dual-task situation, driving while talking on a mobile phone (Briem & Hedman, 1995, Strayer, Drews, & Crouch, 2006; Strayer & Drews, 2007; Strayer & Johnston, 2001). For example, Strayer et al. (2006) compared the performance of drivers who were drunk to those who were talking on a phone. Although the pattern of behaviour for each group was different (i.e. drunk drivers exhibited more aggressive behaviour by driving closer to vehicles in front and braking harder, whereas those conversing on a cell phone showed delayed braking responses) both groups showed severe impairments in driving performance. While it may come as no surprise that alcohol impairs driving performance, the worrying finding was that participants who talked on a mobile phone were also involved in more accidents than when they were not talking on the phone.

What underlies these effects of distraction? The central concept invoked is *selective attention*, our ability to focus limited processing resources on some stimuli while ignoring others. Why does talking on a mobile phone disrupt a person’s driving ability? Strayer and Johnston (2001) suggest that telephone conversations reduce the amount of attention which 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 phone or a hand-held device (Strayer et al., 2006; Strayer & Johnston, 2001). Furthermore, Strayer & Drews (2007) investigated participants’ memory for objects that they had fixated while performing a simulated driving task in two conditions: one when they were talking on a mobile phone and one when they were not. 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 inattentional blindness (Mack & Rock, 1998). Additional support for this hypothesis came from a separate experiment in which they measured event-related potentials (ERPs) elicited during driving either while talking on a phone or not. They found that the amplitude of the P300 component was smaller in the conversation condition than in the control condition. Since the P300 is assumed to reflect the allocation of attention to a task (Sirevaag et al., 1989) this result suggests that telephone conversation disrupted attention during driving.

However, while attentional impairments are one route to disrupted memory, we cannot necessarily infer attentional impairment from reduced memory performance. For example, it could also be argued that the act of talking on a mobile phone interfered with updating working memory for later recall rather than attention per se; P300 amplitude is also thought to reflect updating of working memory (e.g. Donchin & Coles, 1988). Since there have been no direct tests of the effect of telephone conversation on visual attention, 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 updating memory).

Our goal was to directly test 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 while all of the items move independently for an extended period of time, which can be several seconds or several minutes (Wolfe, Place, & Horowitz, 2007). The standard result is that participants can track multiple targets, with a capacity around 3-5 items (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 a complex motor or task switching component. 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 physically distinguish targets from distractors.

As we noted 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 complete concurrently in order to successfully navigate a vehicle without accidents. For example, when driving, as well as having to be visually aware of their environment (the attentional factor) people have to concurrently perform other tasks such as manually respond to the curvature of the road (by adjusting the steering wheel), update information from side and rear-view mirrors, as well as control the speed of the car using the break and accelerator pedal. Telephone conversation might hurt driving by interfering with any of these sub-tasks individually, or perhaps the ability to switch attention among them. If phone conversation reduces MOT performance, then we can confidently claim that telephone conversations impair visual attention. However, if the MOT paradigm is immune to this interference, then the problem may be more of a purely central executive nature.

In Experiment 1, we measured the dual-task deficit in MOT performance while participants engaged in a telephone conversation (Experiment 1a), compared to the dual-task deficit induced by listening to a narrative (Experiment 1b). We found that telephone conversations did interfere 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 generating speech 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 having to generate new words did. Thus, the interference of conversing during an attentional task is not a low-level motor interference but a more global impairment in cognitive processes needed for sensible and meaningful conversation. Put together these data have implications for why telephone conversations negatively affect 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/hour for their time.

Each experiment (1a, 1b, and 2) involved twelve 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.

Multiple Object Tracking

The MOT procedure was identical for all three experiments. The MOT tasks were conducted on a Macintosh computer running MacOS 9.2, controlled by Matlab 5.2.2

and the Psychophysics Toolbox, version 2 (Brainard, 1997; Pelli, 1997). The stimuli were eight dark grey disks subtending 1.5 degrees visual angle at a viewing distance of 57 cm. The background was a uniform light grey.

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. Disks were initially assigned a random velocity vector and then followed a repulsion algorithm which ensured that disks never occluded one another. The algorithm resulted in unpredictable, random trajectories. Disk speed averaged 6.7°/s, with a standard deviation of 3.2°/s. After 3.0 s, one of the eight disks turned red. Participants were asked to respond to whether the red disk was a target or not by pressing one of two keys (the ‘a’ key and the quote key). Participants were asked to respond as quickly and accurately as possible.

Dual-tasks

In Experiment 1a, there was one dual-task condition, the *telephone conversation* task. In this condition, participants engaged in a telephone conversation with an experimenter in a separate room while completing the MOT task. The conversations were meant to be as naturalistic as possible, so there was no explicit template. Topics of conversations included, but were not limited to, hobbies, what people did on their weekends or vacations etc. The main stipulation of 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 deficit in performance could not be attributed to motor interference. Following the experiment, participants were asked if they ever spoke on a cell phone while driving.

In Experiment 1b, the dual-task condition was the *narrative* condition. In this condition, participants listened to an audio recording of part of the story “Dracula” by Bram Stoker while completing the MOT task. The narrative was taken from the lesser-known Chapter 1 of the novel so that participants were unlikely to be familiar with this part of the story. Participants were told to pay attention to the story since they would be asked to answer questions about the prose after they completed the condition. The purpose of the questions was to make sure that participants had actually paid attention to the passage. The story was presented to the participants over a headset while they were performing the MOT task.

In Experiment 2 there were three dual-task conditions: *telephone conversation*, *shadowing* and *generation* (c.f. 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 (for example, if the experimenter said the word ‘green’ the participant would have to repeat back the word ‘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 (for example, if the experimenter said the word ‘green’ the participant would have to generate a new word beginning with the letter ‘n’). In both the shadowing and generation conditions the presented words came from a previously generated list made up of four and five letter words and presented at a rate of approximately one word every four seconds. The word-lists were randomly shuffled for each participant. In all experiments, conditions were counterbalanced across participants, and each condition consisted of five practice trials followed by fifty experimental trials. In Experiment 2 (but not in Experiment 1) all conditions were digitally recorded using Audacity 1.2.5 software (audacity.sourceforge.net).

Data Analysis

We analyzed reaction time (RT) and accuracy. RTs less than 200 ms or greater than 4000 ms were removed as outliers. This led to the removal of less than 1% of the data for Experiment 1a, no data in Experiment 1b and 1.4% of the data in 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, 2004). Error bars on all figures denote within-subject 95% confidence intervals (Loftus & Masson, 1994).

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

In Experiment 1b, eight out of twelve participants answered all the questions about the story correctly. The other four participants made only one mistake. We therefore assume that all participants were actively listening to and comprehending the story. In Experiment 1a, we assume that participants and the experimenter made equal contributions to the conversation. In Experiment 2 we were able to verify this assumption by analyzing the audio recordings: participants spoke on average for 50% of the time while the experimenter spoke for 49% of the time (the remaining time was taken up by non-verbal noise, such as laughter). Accuracy in the shadowing and generation tasks was also high (participants showed 92%, SE +/- 2%, and 89%, SE +/- 2%, correct respectively). Thus it is clear that in all dual-tasks 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, bad performance 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 statistically differ from the corresponding single task baseline (all ts < 1, ps = n.s.). The telephone conditions 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, $p < 0.05$) and accuracy was poorer (t(11) = 2.5, $p < 0.05$) than in its single task baseline, demonstrating a dual-task deficit. The telephone conversation interfered substantially with MOT performance in a way that actively listening 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 a word back in the shadowing condition does not produce any dual task interference. Performance here was not statistically different to that of the single task condition in either speed (t(11) = -1.5, p = n.s.) or accuracy (t(11) = 1.2, p = 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 (RT: t(11) = - 2.9, $p < 0.05$; accuracy: t(11) = 6.8, $p < 0.01$) and generation condition (RT: t(11) = - 7.3, $p < 0.05$; accuracy: t(11) = 6.3, $p < 0.01$) compared to 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, p = n.s.). However, participants were slower in the generation condition than in the telephone conversation condition (t(11) = -4.5, $p < 0.01$). There may be two reasons for this. Perhaps generation is more difficult than conversation. If so, it will require more resources so that fewer were available for the MOT task. Alternatively, participants may simply be 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 severely impaired compared to when participants were performing the MOT task alone.

Figures 1 and 2 about here

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 set of tasks, requiring not only visual attention but visuo-motor 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, & Johnston, 2003; Strayer & Drews, 2007) and change detection (McCarley et al., 2004). However, our data directly demonstrate that telephone conversation impairs performance on a sustained visual attention task (MOT). MOT is an excellent test of sustained visual attention, since participants need to continually attend 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 listening to an engaging narrative nor shadowing imposed costs on MOT performance. However, conversation and word generation, which both 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 ms, 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 miles/hour to travel an additional 18.5 feet (more than the length of the average car) before braking. The effect of listening to the radio, or a book on tape, would be about

1.8 feet (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 deep linkage between the brain systems that orient visual attention and those which orient auditory attention (Ward, McDonald, Golestani, & Wright, 1998). It is known that auditory dual-tasks can interfere with encoding and recall for visual stimuli (Dell'Acqua & Jolicoeur, 2000; Herdman & Friedman, 1985; Jolicoeur, 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 & Shapiro, 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 on both purely visual attention resources and amodal or central 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, since 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' (1984) Multiple Resource Theory hypothesized that will be a larger dual-task cost associated with tasks that share common components than those that do not. More specifically, the theory predicts that there should be a higher dual-task cost between two tasks that share the same modality (i.e. two visual tasks) than two tasks presented in separate modalities (e.g. a visual and an auditory task; Wickens et al., 1983). However, we found a large dual-task cost even through 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, 2002). While 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 & Boer (2006) found that, in a driving simulation task, participants were slower to break 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 we found our bottleneck in this paper to occur at a slightly later stage than that of Levy et al. (Footnote 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 will suffer.

Another point to note is that talking on a telephone may have a social element that purely listening to an auditory narrative does not have. Participants may feel more social pressure to maintain a conversation than they would do to listen to an auditory message (Footnote 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 actually 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 they 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") which 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 (c.f. Grabowecky, Iordanescu, & Suzuki, 2007), but is at the mercy of her interlocutor. For this reason, conversations with passengers are generally less dangerous than mobile phone conversations, since passengers may also be attending to the difficulty of the driving task and can modulate their conversation accordingly.

In summation, this paper again points to the dangers of talking on a telephone while driving. New to the literature is the fact that telephone conversations impair sustained visual attention. When this is put together with the idea 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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Footnotes

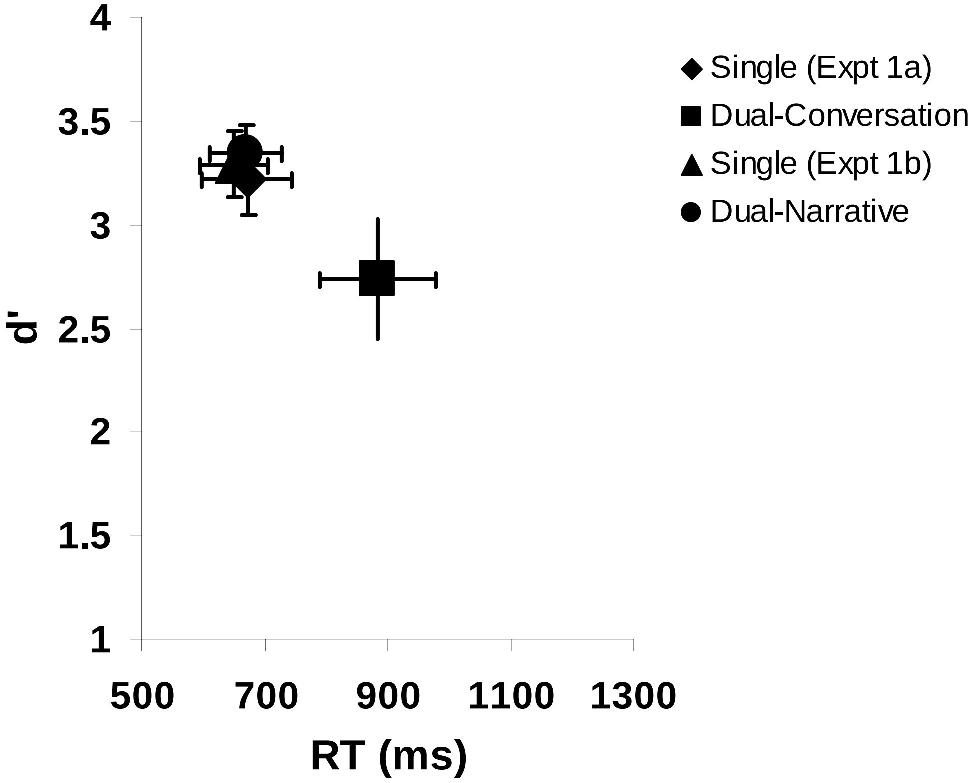
1) Presumably due to the different experimental demands.

2) We would like to thank an anonymous reviewer for this suggestion.

Figure Legends

Figure 1: Speed-accuracy plots of Experiment 1. RTs are plotted on the x-axis, d’ 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-subject confidence intervals (Loftus & Masson, 1994).

Figure 2: Speed-accuracy plot of Experiment 2. RTs are plotted on the x-axis, d’ 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-subject confidence intervals (Loftus & Masson, 1994).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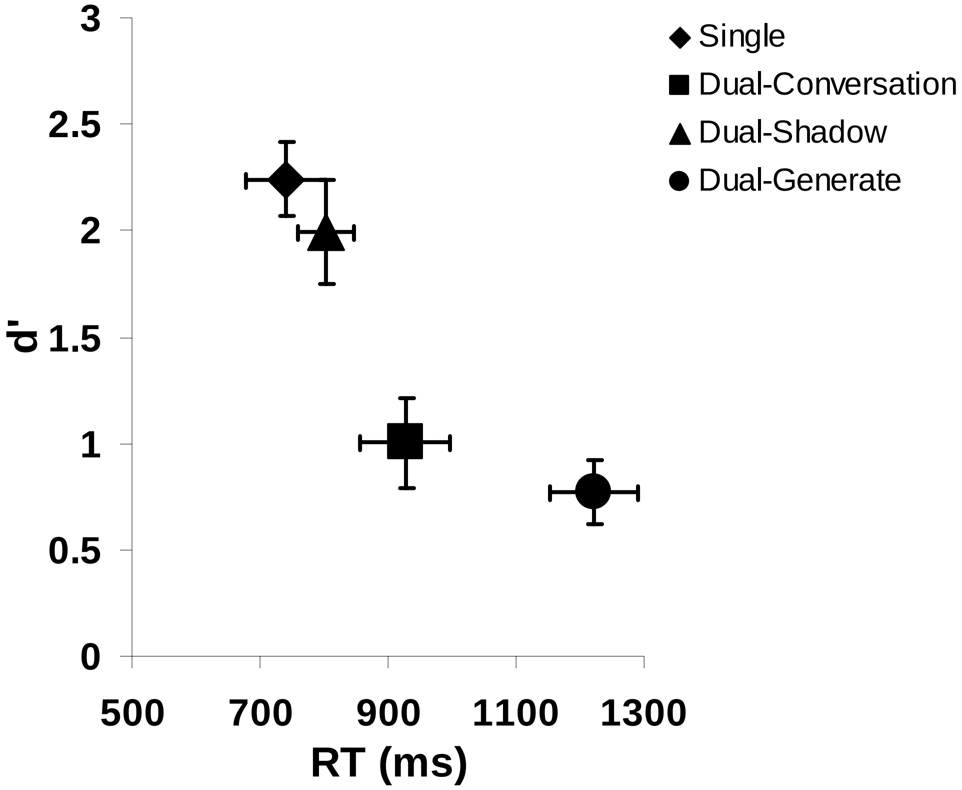
■ Dual-Conversation
▲ Single (Expt 1b)
● Dual-Narrative

Figure 1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1.5
1
0.5
0
d'
500
700
900
1100
1300
RT (ms)
◆ Single
■ Dual-Conversation
▲ Dual-Shadow
● Dual-Generate

Figure 2