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The Crosstalk Hypothesis: Why Language Interferes With Driving

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Performing two cognitive tasks at the same time can degrade performance for either domain-general reasons (e.g., both tasks require attention) or domain-specific reasons (e.g., both tasks require visual working memory). We tested predictions of these two accounts of interference on the task of driving while using language, a naturally occurring dual task. Using language and driving a vehicle use different perceptual and motor skills. As a consequence, a domain-general explanation for interference in this dual task appears most plausible. However, recent evidence from the language processing literature suggests that when people use language with motor content (e.g., language about actions) or visual content (e.g., language about visible objects and events), they engage their motor and perceptual systems in ways specifically reflecting the actions and percepts that the language is about. This raises the possibility that language might interfere with driving for domain-specific reasons when the language has visual or motor content. To test this, we had participants drive a simulated vehicle while simultaneously answering true–false statements that had motor, visual, or abstract content. A domain-general explanation for interference would predict greater distraction in each of these three conditions compared with control, while a domain-specific explanation would predict greater interference in the motor and visual conditions. Both of these predictions were borne out but on different measures of distraction, suggesting that language-driven distraction during driving and dual tasks involving language in general may be the result not only of domain-general causes but also specific interference caused by linguistic content.

Keywords: dual tasks, driving, mental simulation, language comprehension

In 1910, Lars Magnus Ericsson (the Swedish founder of the eponymous telephone manufacturing company) installed a telephone in his car. Limitations of current technology meant that he could only use it when he parked near accessible telephone wires and manually connected the phone to the national telephone network (Meurling & Jeans, 1994). Despite the obvious inconvenience, having to stop his car to talk might have ultimately been in his best interest. In subsequent years, as driving and telephoning have become more pervasive, both independently and in combination, a host of studies have shown that driving while using a telephone impairs the successful performance of both tasks (I. D. Brown, Tickner, & Simmonds, 1969). Most important, drivers who are also using a telephone are slower to brake in response to a stimulus (Alm & Nilsson, 1995; Lamble, Kauranen, Laakso, & Summala, 1999; Lee, McGehee, Brown, & Reyes, 2002; Levy, Pashler, & Boer, 2006; Strayer, Drews, & Johnston, 2003b) and worse at controlling their steering (Brookhuis, De Vries, & De Waard, 1991; but cf. Kubose et al., 2005).

Driving and conversation are both complex, multimodal, attention-demanding tasks, so interference between them is not particularly surprising. Indeed, driving while talking on a cell phone is just one example (albeit one that can have particularly important consequences) of a dual task. Dual tasks are discussed in more detail below, but in general, some pairs of tasks are hard to perform simultaneously (the patting-the-head-while-rubbing-the-belly class) while others are relatively easy (the walking-while-chewing-gum class). Moreover, as discussed below, there is a range of explanations of why and when dual tasks interfere. But driving-and-conversing is clearly of the former, interfering type. The question is why; why does conversing while driving result in degraded performance in one or both tasks? I. D. Brown et al. (1969) list two candidate reasons. First, they argue,

> Having to use a hand microphone and having to manipulate push buttons to make or take a call will be inconvenient and may impair steering, gear changing, or other control skills. (p. 419)

The possibility that manipulating a device will interfere directly with the motor control required for driving also has a second component that has become more prominent as screens on mobile devices have become more important components of the interface—namely, perceptual interference. Looking at a display demonstrably interferes with perception of one's surroundings by dint of the fact that the driver is not able to perceive both the

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display and the environment with high acuity at the same time through their visual channel (Wickens, 1980). This type of direct perceptual or motor interference is a good candidate explanation for the impaired driving observed during telephoning. Something like this reasoning has resulted in legislation in a number of states prohibiting the use of telephone handsets during operation of motor vehicles (Governors Highway Safety Association, 2012).

However, there is reason to believe that direct sensory and motor interference is only part of the story. I. D. Brown et al. (1969) also proposed a second potential source of interference:

> A more important and lasting problem arises from the hypothesis that man can be considered to act as a single communication channel of limited capacity. The prediction from this hypothesis is that the driver will often be able to telephone only by switching attention between the informational demands of the two tasks. Telephoning could thus interfere with driving by disrupting visual scanning, since visual and auditory information would have to be transmitted successively. It could also interfere by overloading short-term memory and impairing judgment of relative velocity, which depends upon integration of successive samples of visual information. (p. 419)

Holding a conversation over a telephone (even without acting on or perceiving a device) and driving a car might simply be incompatible tasks, or at least tasks that are not so compatible as to be performable simultaneously without impairment. A number of studies have provided supporting evidence for this contention; drivers display signs of distracted driving even when using hands-free devices, with their limbs and eyes fully committed to the driving task at hand (Strayer & Drews, 2007; Strayer, Drews, & Crouch, 2006; Strayer, Drews, & Johnston, 2003a). Talking on a telephone and driving appear to be dual tasks that interfere not merely for direct perceptual and motor reasons but also for other reasons as well. However, as we will see, while the literature on dual tasks provides several candidate explanations for this type of interference, it is still unknown which apply to this particular case.

What happens when people attempt to perform multiple tasks at the same time has been the object of intense scrutiny for many decades under the rubric of dual-task or multitask studies. Broadly speaking, there have been at least two sorts of proposed explanations for dual-task interference (Strayer & Drews, 2007). The first type depends on generalized processing constraints. These argue in various ways that people only have limited computational or attentional resources to spread across the various tasks they are engaged in; when two tasks require more of these resources at the same time than are available, performance on one or both tasks is impaired. Accounts in this tradition may differ in terms of whether they ascribe the impairment to serialization of the relevant cognitive processes or to sharing of resources simultaneously, but they all share the general claim that whatever the two tasks, the criterion that contributes to interference is an independent and domain-general measure of the attention or computational bandwidth required to perform each task independently (Kahneman, 1973; Navon & Gopher, 1979). Obviously, this generalized interference class of explanation could very easily apply to driving and telephoning to the extent that each task individually demands more attention or computational resources than can be shared in real time with the other.

A second proposed explanation ascribes interference to domain-specific interference in the use of particular pieces of mental machinery. For instance, it could be that visual perception is impaired during simultaneous visual imagery because the two tasks both require use of the visual system, which simply cannot as successfully perform two different tasks at the same time (e.g., see Bergen, Lindsay, Matlock, & Narayanan, 2007; Craver-Lemley & Arterberry, 2001; Perky, 1910; Richardson, Spivey, McRae, & Barsalou, 2003). On this type of explanation, the more similar two tasks are, in terms of the specific processing required to perform them, the more interference we should observe (James, 1890). Such domain-specific explanations are often couched in terms of code conflict (Navon & Miller, 1987); if two tasks use similar representational codes (e.g., perceptual working memory or motor control signals) that need to be engaged at the same time, then they can come into conflict. When two tasks use the same codes and they conflict, they can produce "crosstalk," impaired performance on one or both tasks (Pashler, 1994).

When this second, crosstalk-based explanation is applied to driving and talking on a telephone, it may superficially seem less plausible than a more domain-general explanation. After all, the act of conversing by itself (e.g., when drivers are not looking at or manipulating a device because they are using a hands-free setup) requires auditory processing of the speech signal and motor control of the vocal tract, whereas driving predominantly recruits other systems dedicated to visual perception and motor control of the hands and feet (or foot). Of course, driving and telephoning also engage other cognitive faculties, like attention, planning, and memory, but to the extent that these resources are domain-general—that is, not specific to perceiving in a particular modality or moving a particular effector—any interference that their simultaneous use produces reduces to an explanation of the first, domain-general type, described above.

It might seem to follow that if driving and conversing with a hands-free system interfere with each other, this must be chalked up to some sort of domain-general interference. However, recent developments in the language comprehension literature suggest an alternative explanation. Over the past decade, a number of findings have emerged, converging on the conclusion that comprehending language about actions leads people to engage their motor systems, as measured by behavioral (e.g., Glenberg & Kaschak, 2002), brain imaging (e.g., Tettamanti et al., 2005), and magnetic interference paradigms (e.g., Pulvermüller et al., 2005). The motor routines that are covertly activated during comprehension correspond to the content of the language people are processing. For instance, language about foot actions leads to activation of parts of the supplementary motor area and the motor strip that control foot actions, while language about hand and mouth actions produces activity in hand- and mouth-dedicated motor areas, respectively.

Likewise, just as language about actions results in the engagement of motor systems, so language about visually or auditorily perceptible entities and events leads comprehenders to activate their visual or auditory systems, again in ways that directly reflect the content of the language they're processing. For instance, language about objects moving away from or toward a perceiver results in engagement of visual representations of movement away from or toward the self; described objects are visually represented with contextually appropriate shape (Zwaan, Stanfield, & Yaxley, 2002), orientation (Stanfield & Zwaan, 2001), color (Connell, 2007), and location (Bergen et al., 2007). These findings have been collectively interpreted to suggest that people comprehending language are engaging mental simulations of the described entities and events, using brain systems dedicated to action and perception. While there has been less work on the engagement of perceptual and motor systems during the production of speech, there is limited evidence from gesture and production studies that producing language about actions (just like understanding language about actions) engages the motor system (Hostetter & Alibali, 2008).

There remains substantial debate in the literature as to exactly what the functional role is of this motor and perceptual system activation during language comprehension (e.g., Mahon & Caramazza, 2008), let alone language production. But the undisputed and recurrent finding, from a variety of methods, is that language about perceivable entities and events affects simultaneous or subsequent real perception and that language about actions affects simultaneous or subsequent motor action (Bergen, 2007). Regardless of the function of this mental simulation, it could be responsible for code conflict—modality-specific crosstalk between driving and conversing. When people are conversing about topics that engage perceptual systems (language about visible or audible entities and events) or motor systems (language about performable motor actions), they might have a harder time perceiving the real world around them or performing the requisite actions involved in driving.

The upshot is that the dual tasks of using language and driving a vehicle might in fact produce domain-specific crosstalk if the language in question engages perceptual and motor systems also required for driving. Thus, it could be domain-general or domain-specific interference that is responsible for some part of the impairment that telephoning drivers display. At present, no work directly compares predictions of these two viable explanations. Yet such a comparison would be quite valuable, for three reasons.

First, while we do know that conversation interferes with driving (and the reverse), we simply do not know why. It is possible that the interference results from domain-general dual-task interference, but it is also possible that language-content-driven, modality-specific crosstalk is responsible. If the latter is true, this suggests by extension that content-driven code conflict may be a factor in other dual tasks that involve language.

A second reason to compare a domain-general account of interference and a domain-specific crosstalk hypothesis is to assess whether mental simulation, which purportedly plays a role in comprehension and production of language, is also measurable in more ecologically valid conditions than those of experiments usually conducted in the field. Results from traditional laboratory experiments only bear implications for habitual cognition to the extent that the tasks participants perform in them are externally valid. Arguably, the typical setups of laboratory experiments performed in the area (participants usually hear or read sentences, then press buttons to perform particular motor responses or in response to particular percepts) are less ecologically valid than laboratory recreations of naturally occurring dual tasks, like language use during driving.

A third and final reason has to do with public safety. According to the National Highway Traffic Safety Administration (2010), in 2009 there were 448,000 people injured and 5,474 people killed in crashes in which the police report listed at least one driver engaging in a distracting activity, such as talking on a cell phone. Ascertaining why language interferes with driving will tell us whether this interference is an unavoidable product of this real-life dual task, which will in turn will allow us to assess the safety of using a telephone, including hands-free devices, while driving.

In the experiment described below, we tested predictions of these two accounts. If the interference of language on driving has a domain-general explanation, then using language ought to impair driving regardless of what the language is about. On the other hand, the crosstalk hypothesis predicts that language about motor and visual content specifically interfere with driving behavior above and beyond any eventual impairment produced by meaningful language in general.

Method

Participants

There were two versions of the experiment, described below. One hundred forty-five undergraduate students participated in one version or the other for course credit. Of these, 44 were excluded because they performed the language task with accuracy lower than 80%, and eight were excluded because they were unable to complete the experiment, often due to motion sickness. The remaining 93 participants (50 in Version 1 and 43 in Version 2) ranged in age from 18 to 32 with an average age of 23.2. Forty-six participants were female and 47 were male. All participants had normal or corrected-to-normal visual acuity, no known neurological disorders, and a valid driver's license at the time of the study. All participants were native English speakers or had native-like fluency.

Procedure

A PatrolSim high-fidelity driving simulator, illustrated in Figure 1 and manufactured by GE-ISIM, was used in the study. The simulator is composed of five networked microprocessors and three high-resolution displays providing a 180° field of view. The dashboard instrumentation, steering wheel, gas pedal, and brake pedal are from a Ford Crown Victoria sedan with an automatic transmission. The simulator incorporates proprietary vehicle dynamics, traffic scenario, and road surface software to provide realistic scenes and traffic conditions.

Figure 1. PatrolSim driving simulator used in the experiment.

Before the experiment began, participants were trained on the operation of the simulator. They were instructed to follow a lead vehicle at approximately 40 m (i.e., a safe stopping distance at highway speed). They then completed two adaptation scenarios in which they were required to follow the lead vehicle at the specified distance. If they drifted too far outside the target distance, a horn sounded until they corrected their following distance. (Auditory feedback was not provided during the subsequent experiment itself.) The training session lasted approximately 10 min.

For the main experiment, a freeway road database was used to simulate a 10-mile (16.1-km) multilane interstate with on- and off-ramps, overpasses, and two- or three-lane traffic in each direction. Daytime driving conditions with good visibility and dry pavement were used. A pace car, programmed to travel in the right-hand lane, braked intermittently throughout the scenario. Distractor vehicles were programmed to drive between 5% and 10% faster than the pace car in the left lane, providing the impression of a steady flow of traffic. Measures of real-time driving performance, including speed, distance from other vehicles, and braking, were sampled at 60 Hz and stored for later analysis.

To investigate effects of language use on simultaneous driving performance, participants drove along the same roadway in four different language conditions in a block design. Language condition was a within-participants variable, and the order of the four conditions was counterbalanced across participants. In each of the three critical language conditions, participants heard 32 prerecorded single-sentence statements presented through the simulated car speakers. Half were intended to be true and half false.

In the motor condition, sentences had motor content (e.g., "To open a jar, you turn the lid counterclockwise"). Motor language is known to interact with actual motor control, and fine details of described and performed motor actions seem to make a difference, including hand shape (Masson, Bub, & Warren, 2008; Wheeler & Bergen, 2010), direction of motion (Glenberg & Kaschak, 2002), and so on. All of the motor sentences we created differed from the motor tasks required for driving in at least one and often several dimensions. The visual condition presented sentences with salient visual content (e.g., "The letters on a stop sign are white"). The abstract condition used sentences with less clear visual or motor content (e.g., "The capital of North Dakota is Bismarck"). In designing these abstract sentences, we were well aware of the difficulty of finding language that does not plausibly have any perceptual or motor content. We tried to minimize the perceptual and motor content of sentences in this condition by using questions about history, geography, and government (some adapted from the U.S. citizenship exam). Nevertheless, there is evidence that people engage their perceptual and motor systems even while understanding language about arguably abstract concepts like time (Boroditsky, 2000), transfer of information (Glenberg & Kaschak, 2002), and power (Maner, Kaschak, & Jones, 2010). For this reason, our abstract condition was not a pristine test of what happens when perceptual and motor simulation is not engaged by language, but it did at the very least give perceptual and motor content a less prominent role. By the same token, some people seem to be strongly biased toward visual representations of events; as a result, though we did our best in designing motor statements, for many people these could well have strong visual effects as well. This could result in the motor and visual conditions acting similarly.

In each of these conditions, participants were instructed to judge the truth or falsity of the sentences and respond by saying "True" or "False" immediately after hearing the sentence and making their judgment. The fourth, control condition was designed as a baseline. In this condition, participants heard two sentences, "Say the word *true*" and "Say the word *false*," each repeated 16 times. Their task was simply to comply with the sentence.

Immediately (500 ms) before the offset of each of the 32 critical stimuli, the lead vehicle braked (its brake lights went on, and it gradually decelerated). This allowed us to measure the time participants took to respond to a braking event while in the process of comprehending a sentence. To ensure that participants did not come to expect a braking event at the end of each sentence, we also included 22 filler sentences in each condition that were not synced with a braking event.

To investigate whether there are distinct effects of language comprehension and language production, we conducted a second version of the same experiment as well, in which participants were asked not merely to respond with *true* or *false* but to repeat the true sentences (e.g., "True, the capital of North Dakota is Bismarck"), and to produce corrected versions of the false ones (e.g., "False, the letters on a stop sign are white."). Results from both versions are discussed in the Results section, below.

We wanted to ensure that any measured effects of impaired driving that participants displayed did occur because of cognitive interference and not physical interference. Indeed, it might have been a good strategy, when confronted with true–false statements about actions, for participants to actually engage their skeletal muscles to produce gestures as part of their attempts to answer true–false questions. To avoid this potential problem, the experimenters instructed participants to keep their hands on the wheel at all times and reminded them to do so if they were observed to take their hands off the wheel at any point. So actual physical enactment of the described actions, where participants took their hands off the wheel, could not account for any effects of motor or visual language.

Materials

To ensure that sentences in the three critical conditions were equally easy to process and to respond to correctly, we created 124 sentences in three language conditions (visual, motor, abstract) and two truth conditions (true, false; see the Appendix). These were subjected to norming with 11 native speakers of English who did not participate in the main experiment. Participants heard each sentence (the order of presentation was randomized for each participant) and were asked to press a button (*T* or *F*) to indicate whether it was true or false. Dependent measures were response time and accuracy.

On the basis of these measures, we selected 16 true and 16 false sentence stimuli in each sentence condition that produced the most similar mean response times and accuracy across conditions. The resulting 96 stimuli did nevertheless vary somewhat along both measures, as seen in Table 1 below.

We conducted a 2 (veracity) × 3 (language condition) repeated-measures analysis of variance (ANOVA), which revealed no significant effect on response time (RT) of veracity, $F(1, 10) = .78$,

Table 1
Mean Accuracy and Mean Reaction Time (RT) in the Three Language Conditions in the Norming Study

	True		False		Total	
Language condition	Accuracy (*SE*)	RT (*SE*)	Accuracy (*SE*)	RT (*SE*)	Accuracy (*SE*)	RT (*SE*)
Abstract	84% (3.4%)	1,029 (220)	85% (3.9%)	1,067 (226)	85% (2.8%)	1,047 (217)
Motor	78% (3.3%)	1,165 (152)	94% (1.4%)	1,075 (123)	86% (1.7%)	1,120 (133)
Visual	90% (3.3%)	1,094 (186)	92% (1.7%)	1,009 (140)	91% (1.9%)	1,052 (159)

Note. Reaction times are in milliseconds.

$p = .40$, or language condition, $F(2, 20) = .32$, $p = .73$. There was also no interaction between these factors, $F(2, 20) = .66$, $p = .53$.

In terms of response accuracy, participants responded relatively accurately to all sentence types (more than 80% accurate). We conducted a 2 (veracity) × 3 (language condition) repeated-measures ANOVA for accuracy. There was a main effect of veracity, $F(1, 10) = 13.85$, $p = .01$, and a main effect of language condition, $F(2, 20) = 4.02$, $p = .03$. There was also a significant interaction between these factors, $F(2, 20) = 3.69$, $p = .04$. Pairwise comparisons revealed that among the language conditions, the only significant difference was between motor sentences and visual sentences ($p < .05$). In the Discussion, we revisit this difference and argue that it is unproblematic for our results.

Measures

The two dependent measures of driving performance for this study were braking reaction time (i.e., the mean time taken to apply brake pressure when the pace car's brake lights came on) and following distance (i.e., the mean distance between the participant's vehicle and the pace car). These measures have been used in numerous driving studies (e.g., Horrey & Wickens, 2006; Watson & Strayer, 2010; Watson, Lambert, Cooper, Boyle, & Strayer, in press) and are generally seen as reliable indicators of driving distraction.

Brake reaction time was determined by measuring the interval between the onset of the brake lights on the lead vehicle and the depression of the brake pedal by the participant. Following distance was measured as the distance between the rear bumper of the lead vehicle and the front bumper of the participants' vehicle. Participants were instructed to maintain a 40-m following distance and to respond with alacrity when the lead vehicle brake lights were illuminated. (As mentioned above, participants received training on proper following distance in the training scenarios that preceded the main experiment.)

Prior research has found that both braking reaction time and following distance are very sensitive to driver distraction and in both cases increase as drivers divert attention from the roadway (Strayer, Watson, & Drews, 2011). The lengthening of reaction time with increased distraction has been shown to increase both the likelihood and severity of crashes (T. L. Brown, Lee, & McGehee, 2001). While it is clear that following distance increases with distraction, it is less clear exactly why this is the case. Previous work has argued that elongated following distance may be produced by a failure of goal maintenance (Watson et al., in press). As we make clear in the discussion, there is an alternative interpretation of increased following distance—that it is a strategic response in the face of increased cognitive load.

The main point, however, is that our two dependent measures, braking reaction time and following distance, index different aspects of driving distraction. To brake quickly when a pace car's brake lights come on, a driver needs to be visually attending to the pace car, has to be able to perceive the brake lights come on, and has to reflexively activate the overlearned motor response associated with braking. Effectively, it is a visually triggered reaction task. It has thus been argued that braking reaction time measures relatively low-level visual attention and motor control, part of the "operational level" of vehicle control (Drews, Pasupathi, & Strayer, 2008). By contrast, maintaining a safe following distance behind a pace car throughout a driving session involves a more complex and higher level set of cognitive operations. If, as this previous work has argued, following distance indexes successful goal maintenance, then maintaining a target distance requires the driver to continuously keep in working memory the optimal distance while evaluating the current following distance and comparing the two. On this account, the reason that following distance increases with distraction is the following: As the speed of the lead vehicle fluctuates, the distracted driver is slow to respond to acceleration of the lead vehicle because he or she has difficulty maintaining the target distance in mind and in calculating the difference between current distance and target distance. But even the somewhat distracted driver responds to brake lights of a lead vehicle by slowing his or her own vehicle. So quick braking but slow accelerating leads to an increased mean distance. As a result of all of this, following distance is typically described as a higher, "tactical level" measure of vehicle control (Drews et al., 2008).

The domain-general and crosstalk hypotheses make different predictions about how the various language conditions will affect these two measures. First, if language use interferes with driving because both require domain-general resources (above and beyond the auditory processing and motor control required for hearing a sentence and produce a response) then all three critical conditions (motor, visual, and abstract) should produce greater indications of driver distraction than the control condition (in which participants did not have to do much processing of the meaning of the utterances, and language production was highly predictable). Second, if using language interferes with driving in part because of crosstalk—code conflict induced by language with perceptual or motor content—then the visual and motor language conditions should display greater indications of driver distraction than not only the control condition but also the abstract condition. These two effects may also manifest themselves differently on the two dependent measures, which will allow us to determine what sorts of cognitive processes are interfered with by language comprehension in general and comprehension of language with visual and motor content in particular.

Results

There were no significant differences between the two versions on any of the critical measures (in Version 1, as described above, 50 participants responded with "true" or "false" only, whereas 43 participants repeated or corrected each statement in Version 2). As a result, we pooled data from the two versions for all subsequent analyses.

We conducted separate repeated-measures ANOVAs for each of the dependent measures of driving performance. For braking reaction time (i.e., time that the participant took to brake after the lead vehicle's brake lights went on), there was a main effect of language (visual, motor, abstract, control) by participants, $F(3, 273) = 8.73$, $p < .01$, partial $\eta^2 = .09$.[1] Using the Greenhouse-Geisser correction for violations of sphericity produces identical results. We also conducted an analysis by items. To do this, we took as the dependent measure the difference between mean reaction time for an item and the mean reaction time for all items, across all conditions, presented in that same location. (This measure controlled for differences in reaction time due to characteristics of the specific location along the route where each item was presented.) A repeated-measures ANOVA showed a significant effect of language by items: $F(3, 124) = 11.44$, $p < .01$, partial $\eta^2 = .22$. Planned pairwise comparisons using Tukey's honestly significant difference (HSD) for pairwise comparisons indicated that each of the experimental conditions (motor, visual, and abstract) induced greater reaction times than the control condition (all ps $< .01$; all ds > 0.25), in both analysis by participants and items, but there were no other significant differences (see Figure 2).

Following distance (the mean distance the driver stayed behind the lead vehicle throughout the entire drive) also differed depending on language condition. A repeated-measures ANOVA revealed a main effect of language, $F(3, 273) = 3.68$, $p < .05$, partial $\eta^2 = .04$. Again, using the Greenhouse-Geisser correction for violations of sphericity produces identical results. For this measure, the motor and visual conditions led to the numerically greatest following distances, as seen in Figure 3. We again conducted planned pairwise comparisons between conditions using Tukey's HSD. There were significant differences between the visual condition on the one hand and the abstract ($p < .05$; $d = 0.16$) and control ($p < .05$; $d = 0.18$) conditions on the other. No other differences approached significance, although there were small quantitative differences between the motor and control ($d = 0.13$) and motor and abstract conditions ($d = 0.11$), as seen in Figure 3. Uncorrected pairwise comparisons using Fisher's least significant difference revealed that the difference between motor and abstract conditions reached significance ($p = .03$), while the difference between motor and control conditions only approached significance ($p = .09$).

Although mean following distance is the conventional dependent measure in studies of this type, we also looked at variability in following distance. In a repeated-measures ANOVA, we found no main effect of language condition on standard deviation of following distance ($p = .20$). But post hoc pairwise comparisons revealed that the abstract condition produced significantly less variability than the visual or the motor condition (ps < 0.01), while no other differences approached significance.

In addition to these measures of driving performance, we also measured participants' accuracy in the linguistic task (saying "true" or "false" or responding with the correct sentence). Looking only at those participants included in the driving performance analyses above, we found a main effect of language condition on accuracy, $F(2, 184) = 12.1$, $p < .001$. Pairwise comparisons indicated that responses were most accurate in the visual condition (89.8%), which differed significantly from both the motor (86.6%) and abstract (85.9%) conditions. The motor and abstract conditions did not differ significantly from each other. These accuracy numbers are extremely similar to the figures from the norming (visual = 91%, motor = 86%, abstract = 85%). This would make it appear that driving was affected differentially by type of language, but language processing was not differentially affected by concurrent driving. When we include data from all participants, even those who were excluded from the main analysis due to low accuracy, the accuracy figures drop slightly for all three language conditions: visual = 87.5%, motor = 84.9%, abstract = 81.8%. These accuracy rates are all significantly different from each other (ps < 0.05). Interestingly, when we compare the norming and experimental accuracy rates, the most affected sentence types were the Visual and abstract sentence—accurately responding to motor sentences appeared to be affected very little by the dual task. So it may well be the case that language was in fact differentially affected by concurrent driving.

Discussion

To investigate whether language interferes with driving for domain-general reasons or due to crosstalk caused by linguistic

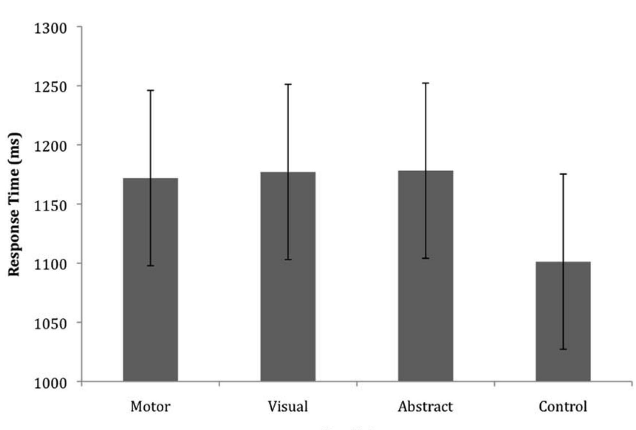

Figure 2. Braking reaction time differed significantly between control on the one hand and motor, visual, and abstract conditions on the other. Whiskers depict 95% confidence intervals.

[1] We also looked at the effect of the veracity (true, false) of the sentence in question. A two-way repeated-measures ANOVA revealed a main effect of veracity ($p < .001$) but did not eliminate the main effect of language ($p < .01$), and there was a nonsignificant interaction, $F(3, 270) = 2.35$, $p = .073$, between these variables.

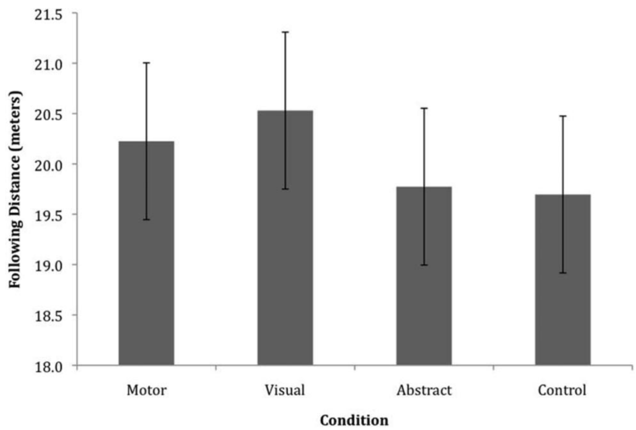

Figure 3. Following distance differed significantly, depending on language condition; visual language produced greater following distances than language in the abstract or control conditions. Whiskers depict 95% confidence intervals.

content, we had participants drive a simulated route in several language conditions. They answered true–false questions that had visual, motor, or abstract content, or they performed a control task, where they were instructed to say the word *true* or *false*. We measured braking reaction time and following distance and found evidence for both domain-general and crosstalk-based interference, but on different dependent measures.

The domain-general interference prediction—that the three critical language conditions would produce greater impairment than the control condition—was borne out in the braking reaction time measure (the time it took drivers to brake when the lead vehicle's brake lights came on). Braking reactions were slower in all three critical language conditions than in the control condition. By itself, this finding confirms previous work demonstrating that language use, even without a handheld device, interferes with successful control of a vehicle. This finding is most compatible with a domain-general account of the interference between the two tasks (Kahneman, 1973; Navon & Gopher, 1979).

However, results from our other dependent measure, following distance, bear out the prediction of the crosstalk hypothesis. Following distance was significantly greater in the visual condition than in the abstract and control conditions, and in the motor condition, it was quantitatively greater than the abstract and control conditions. Following distance has been shown elsewhere to increase with distraction; drivers leave larger buffers between themselves and lead cars when their ability to attend to the environment is impaired (Watson et al., in press). The present following distance results, therefore, appear to indicate greater degrees of distraction for visual sentence (and to a lesser extent, motor sentences) than abstract ones or control. This finding is most compatible with the hypothesis that language use interferes with driving when the linguistic content overlaps with the perceptual (or motor) routines engaged to control a vehicle.

Before turning to why predictions of the two hypotheses showed up on different dependent measures, it is critical to deal with one possible objection to the crosstalk interpretation of the following distance results. Perhaps drivers were more distracted in the visual (and to some extent motor) sentence conditions than in the abstract condition not because of differences in linguistic content, but simply because the visual and motor sentences were harder to understand. The norming results described in the Method section rule this out as a possibility. We reported there that, if anything, visual (and motor) sentences were easier to process than abstract ones. Moreover, if the effect were due to differences in processing difficulty, a difference in distraction ought to have shown up not only on following distance but (and perhaps even more likely) on braking reaction time as well. But there was no such effect observed on braking reaction time. As a result, overall processing difficulty cannot explain the increased following distance in the visual and motor conditions. Instead, increased following distance appears to be the product of driving while processing language of a specific type, namely, language with motor or visual content.

How then can we explain this pattern of results, where any meaningful language increases braking reaction time, but only language with visual (or motor) content increases following distance? As mentioned earlier, these two measures index different aspects of vehicle control. Braking reaction time effectively indexes success on a simple reaction task driven by visual attention to the brake lights of the lead vehicle. This, as argued above, tells us about the degree of the individual's success with low-level operational control of the vehicle. Notably, it is on this dependent measure that we see homogeneous effects of meaningful language processing. Apparently, processing meaningful language saps resources needed to respond quickly to a braking event. These could include attentional resources required for maintaining covert attention to the pace car's brake lights or maintaining actual visual contact with them, or low-level motor control resources responsible for executing the requisite foot movement.

By contrast with braking at the sight of brake lights, maintaining a specific following distance is a higher order task, which requires heavier use of higher level visual and motor memory and planning. To successfully perform the task, the driver has to use visual working memory to compare the current distance from an optimal distance and occasionally plan and then execute appropriate, corrective motor routines (pressing or releasing one of two pedals). Following distance was more severely affected by processing of language with visual and motor content than language with abstract content. This is consistent with the idea that using motor and visual language engages visual and motor systems, which in turn interferes with performing a secondary task that requires heavy, high-level use of these systems, like maintaining following distance.

This pattern of findings affords some insight into exactly why language about vision and motor control interfere with actual vision and motor control. Both the vision and motor systems are organized hierarchically (Fuster, 2000; Van Essen & Maunsell, 1983). If language interferes with perception and action because it uses up low-level visual and motor resources (for instance, primary visual or motor areas), then we should see greater impairment in motor and visual conditions for both the following distance and braking reaction time measures, since both require low-level motor control and visual processing. But this is not what we found. We found instead that visual and motor language interfered more than abstract language only for following distance, which requires perceptual memory and motor planning in addition to low-level vision and motor control. This suggests that it is these higher level perceptual and motor processes that are selectively engaged by language about visible things and performable actions. This finding is compatible with recent work showing that processing language about motor control uses premotor cortex but not primary motor cortex (Willems, Labruna, D'Esposito, Ivry, & Casasanto, 2011).

There are two alternate interpretations of these content-specific differences that are worth exploring. First, they might result from crosstalk not in the brain but in the body. People spontaneously produce bodily gestures while performing a variety of tasks. Especially when asked to make judgments about physical actions or spatial properties of objects, as in the visual and motor conditions, participants might have been inclined to move their hands to find an answer by running actual motor routines using their skeletal muscles. Yet the instructions they were given explicitly asked them to keep both hands on the wheel. So it is possible that the greater indications of distraction we found in the visual and to some extent the motor condition compared with the abstract condition are due to interference, in that participants had to suppress what would otherwise be their preferred means of answering the questions. There is no way, given our data, to disentangle these two explanations—simulation versus suppressed enactment.

A second alternate interpretation of the following distance results is worth discussing here as well. Perhaps increased following distance indexes not difficulty with continuous maintenance of the target distance from the lead vehicle but instead a strategic decision on the part of the driver to leave a greater buffer when experiencing higher cognitive load. The simplest version of this account would predict that those situations in which cognitive load measurably increases—in all three language conditions as measured by reaction time—drivers should also strategically increase following distance. But this simple account cannot be right, because we found a distinct dissociation between reaction time and following distance; the three language conditions equally affected the former but not the latter. Moreover, the variability of following distance increased in the visual and motor conditions compared with the abstract condition, which again suggests that the abstract condition interfered less with successfully following the lead vehicle at the target distance. This means that the strategic explanation would have to be a bit more nuanced. It could argue, for instance, that drivers had the executive resources available in the visual (and to some extent, the motor) condition to increase following distance in response to increased load but that some property of the abstract sentences did not leave these same executive resources available. There are several linking premises that would need to be validated for this explanation to go through—most notably, performing the task in the abstract condition would need to require greater executive resources than the other two language conditions, even though it didn't increase braking reaction time compared with them. We cannot, however, exclude this as a possible account.

Regardless, these findings have a variety of implications. To begin with, results from both dependent measures show that using meaningful language interferes with perception and action. This is not the first study to report this finding, and it is not surprising that processing novel, meaningful sentences would impair driving more than being prompted to repeat a word. In this regard, the new contribution made by this article is to highlight the heterogeneous mechanisms and effects of language comprehension. Language processing interacts differently with other cognitive operations, depending on exactly what the language is about. Linguistic content is processed in such a way that language about perception and action interacts differently with perceptuomotor behavior in dual-task scenarios than language about abstract topics does. The upshot is that in dual tasks, the details of the tasks matter, especially if one of them involves language.

These results also contribute to the ecological validity of work on language comprehension. In the past decade, research on language understanding has started to converge on the idea that comprehenders use perceptual and motor systems to mentally simulate linguistic content (Bergen, 2007; Bergen et al., 2007; Glenberg & Kaschak, 2002; Pulvermüller et al., 2005; Zwaan et al., 2002), but research on this issue has overwhelmingly used less ecologically valid methods than those used in the present study. Participants in typical experiments are asked to press buttons to signal meaningfulness or grammaticality judgments, or to incrementally display an utterance at their own pace. While these studies have produced reliable and replicable results, it is also important to ensure that people display convergent behavior during tasks that are somewhat more similar to real-world behaviors. Driving while using language is a dual task that occurs frequently in the real lives of many individuals, and the fact that we observed an effect of motor and visual language processing on the high-level perceptuomotor task of distance maintenance extends previous experimental findings in this more naturalistic testing ground.

Finally, there are practical ramifications of the finding that different sorts of meaningful language interfere with perception and action in different ways. As language technology becomes faster, cheaper, and more powerful, there is a temptation to embed it more pervasively in designed environments. In automobiles alone, a variety of tools, beginning with wireless telephones, are popping up, including text-to-speech software that can read e-mail and text messages out loud to the driver, and speech recognition software that the driver can use as an interface to an on-board computer. A cautionary note is in order here. Language can be a powerful interface tool for applications like these, but it can also increase cognitive load on the user and impair performance (Lee, Vaven, Haake, & Brown, 2001). In general, evidence that language interferes with other tasks suggests that we need to carefully evaluate whether the benefits offered by increasingly pervasive language technology outweigh the costs to the safe operation of a vehicle. To the extent that language technology does increase cognitive load, engineering solutions that serve to mitigate this effect may be called for. A 75-ms increase in reaction time found in the lab might not seem like a particularly large effect. In the driver's seat, it can have extremely important consequences. Our results show that in the deployment of language technology, we can assume neither that language is zero cost nor that language has a homogeneous cost.

Of course, the language that a driver uses while controlling a vehicle is not restricted to technology-mediated interactions—drivers regularly interact with and overhear passengers as well. There is no doubt that in certain circumstances, drivers can find linguistic interactions with passengers to be just as distracting as technologically mediated ones. But passengers do not seem to disrupt driving across the board (Drews et al., 2008), at least in part because passengers who share context with drivers and have shared interest in the success of the driving provide cues that draw the driver's attention to the roadway at critical times. It is possible that distraction caused by conversation with a passenger is sensitive to linguistic content in the way shown by the work we have reported here, but that remains to be determined.

In this particular case, different types of language have different costs. In line with the crosstalk hypothesis, we observed the greatest following distance when drivers were processing language about visual scenes, and measurably shorter following distances when the language was about abstract topics like history and government. In line with the domain-general hypothesis, reaction times were slower when people were processing any meaningful language at all, regardless of the content, compared with control. Put together, these two findings produce a surprising twist. It is actually not language about visual or motor events that poses the greatest risk to drivers. In both of these conditions, which show elevated braking reaction times, drivers also followed lead vehicles at an increased distance. Instead, it is abstract language that creates the most unfavorable driving conditions—this is where drivers are slow to respond while also driving closer behind the vehicle ahead of them. This outcome was entirely unforeseen by us, but it shows how nuanced the effects of different types of language are when measured on realistic motor control and perceptual tasks.

Conclusion

Using language interferes with perception and motor control for a variety of reasons, including the time pressure implicit in conversational turn taking and the demands of planning and producing novel utterances. The findings reported here illuminate one previously undocumented reason why language impinges on driving. Not only does language interfere with low-level components of driving, because of processing involved in comprehending meaningful utterances, but above and beyond this effect, language with different content interferes more or less with higher level perceptual reasoning and motor planning. Visual language interferes with tactical control of a vehicle more than abstract language, as we have argued, because it induces a code conflict. While spoken language is primarily oral–auditory, its content can vitally engage perceptual and motor systems also deployed for perceiving the environment while driving and responding appropriately. This ought to be true not only for driving but also for dual tasks that involve language in general. To the extent that language engages perceptual and motor systems, there will be code conflict when a participant using that language needs to simultaneously perform perceptual or motor tasks. The lesson to learn from the present work is that language with different content can be expected to have heterogeneous effects. This ought to be as much the case in the driver's seat, in the airplane cockpit, on the bridge of a ship, or in an air traffic control tower as it is in the laboratory.

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Appendix

Critical Sentences

Motor Sentences

To open a jar, you turn the lid counter-clockwise.
To get out of bed, you don't use your hands at all.
When using a fork and knife, the knife is in your right hand.
When you flip a coin, you curl your fingers.
To turn down a light dimmer, you turn it clockwise.
To use scissors, you have to use both hands.
When you type, your thumbs are over the space bar.
Stapling a thick stack of papers requires only your fingertips.
You can pick your nose with your thumb.
You can crush a Kit Kat between your thumb and forefinger.
You can punch a hole in a napkin with a straw.
When wearing flip flops, your heel is held to the rubber.
A paper grocery bag is lighter than a plastic one.
When tiptoeing, you're on the balls of your feet.
When holding a mug, your middle finger sticks out.
When jumping rope, you land on your heels.
To kick down a door, you use the bottom of your foot.
When walking down stairs, your toes land before your heels.
When pushing an elevator button with your index finger, your middle finger curls.
To pull a slot machine lever, you use your left hand.
To turn the volume up on a stereo, you turn the dial clockwise.
When you throw a dart, you squeeze it with your pinkie.
To lift a manhole cover, you only need one hand.
To plug in a lamp, you need two hands.
When you swim with flippers, your toes are pointed.
When you peel a banana, you use two hands.
To balance on a soccer ball, you rotate your ankles inward.
When climbing a rope, you squeeze it with your elbows.
A bottle of wine weighs more than a cup of coffee.
When you ride a bicycle, you pedal with your heels.
You can crush a barbell by stomping on it.
When holding a mobile phone to your ear, your palm covers the key pad.

Visual Sentences

A right angle is 90 degrees.
The Golden Gate Bridge is shiny and silver.
Colorado has borders with both Wyoming and New Mexico.
The southernmost point in Oregon is farther north than all of Utah.
A recliner could fit into the interior of an exercise ball.
On a computer keyboard, the caps lock key is on the right.
A camel has fur on the top of his humps.
An elephant's tail reaches the ground when it's standing.
The longest U.S. border is with Canada.
A normal strawberry is bigger than a normal grape.
A witch's hat is the same shape as an orange traffic cone.
A highlighter could fit in a keyhole.
An Egyptian pyramid is the same shape as the White House.
There's no border between Washington State and Alaska because Canada is between them.
A postage stamp is bigger than a teabag.
The Rocky Mountains are between Utah and California.
You can see pretty well through a glass of white wine.
A straw is thin enough to fit in a pencil sharpener.
A pie crust is about the same shape as a Frisbee.
In terms of land area, Argentina is the largest country in South America.
The Eiffel Tower has four thick metal legs.
Florida has a border with Mexico.
An ant's body is taller than it is long.
You can see sand through a beach towel if you look closely.
A canoe could fit easily inside an airplane hangar.
A used pencil is shorter than a chopstick.
On a computer keyboard, the *a* key is on the left.
A polar bear has white nostrils and eyes.
A poodle has furry hanging ears.
Chickens have feathers on their toes and their beaks.
A painter's ladder could fit in a home refrigerator.
A birthday balloon is typically smaller than a water balloon.

Abstract Sentences

The capital of the state of California is Sacramento.
The Pope was responsible for inventing the Internet.
Germany's currency is currently the Euro.
The American Civil War was fought after the Revolutionary War.
There are 12 wonders of the ancient world.
During his second term, Bill Clinton's vice president was John Kerry.
The major enemies of the United States in the Second World War were Germany and Japan.
The Cold War ended in the 1970s.

(*Appendix continues*)

President John F. Kennedy was assassinated in the ’sixties.
The official currency of Puerto Rico is the American dollar.
There is a total of 100 senators in the U.S. Senate.
To commemorate American independence, France designed our flag for us.
There are three permanent members of the United States Supreme Court.
Among other things, grizzly bears eat fish.
A year is the amount of time it takes the moon to travel around the earth.
The Pilgrims first sailed to North America on the *Santa Maria*.
Scientists who study artifacts to learn about the past are archaeologists.
Photosynthesis, converting light to energy, occurs in the leaves of the plants.
Entomologists are scientists who primarily study insects.
Plato and Aristotle were both French philosophers.
Blimps are filled with a gas called helium.
The United States’s national anthem is the Battle Hymn of the Republic.
The capital of the state of Idaho is Salem.
A bottle-nosed dolphin is a type of fish.
The bombing of Pearl Harbor led the United States to enter the Second World War.
Thomas Jefferson was the primary author of the Declaration of Independence.
At sea level, water boils at 100 degrees centigrade.
The Civil War ended with the onset of the Great Depression.
Jimmy Carter served only one term as president of the United States.
If the president dies, the secretary of state becomes president.
The national languages of Britain are English and Russian.
The Revolutionary War was fought between the American colonists and the French.

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