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How Speech Modifies Visual Attention

IAN SPENCE[1]*, ANDREW JIA[1], JING FENG[2], JONNY ELSERAFI[1] and YING ZHAO[1]

[1]*Department of Psychology, University of Toronto, Toronto, ON, Canada*
[2]*Department of Mechanical and Industrial Engineering, Toronto, ON, Canada*

Summary: Auditory distractions can have serious consequences in critical situations such as driving. Mobile phones, radios, media players, and information devices that interpret and produce speech are increasingly common in vehicles, but the threats to visual attention are not yet fully understood. In three experiments, we found that most speech tasks had relatively small adverse effects on the detection of a briefly presented target among distractors across a 60° subarea of the visual field. Although there was a little impact on detectability, moderately difficult speech tasks slowed responding relative to silence. Our most demanding condition—generating and speaking a word beginning with the last letter of another word—had the greatest effects on accuracy and latency, with responding slowed by about 900 ms. An impairment of this magnitude presents a significant threat to safe driving and calls into question the belief that hands-free voice-controlled devices are the answer to the problem of driver distraction. Copyright © 2013 John Wiley & Sons, Ltd.

Many critical tasks require the rapid and accurate deployment of visual attention even when other activities threaten to disrupt the process. Driving a motor vehicle is a case in point. Because motorists frequently speak and listen while driving, understanding the effect that speech might have on visual attention is not solely of academic interest. In a pioneering study, Redelmeier and Tibshirani (1997) noted that collisions were four times more likely while using a cell phone, relative to other auditory distractions such as listening to a radio. Auditory threats to spatial attention increase the risk of collision in real life (Violanti, 1997, 1998) and simulated environments (Kalkhoff, Gregory, & Melamed, 2009; Strayer, Drews, & Johnston, 2003). The National Safety Council in the USA has estimated that 25% of all crashes are linked to the use of a cell phone while driving (Kolosh, 2009). These findings signal a significant public health problem because 81% to 99% of motorists (Wogalter & Mayhorn, 2005; Nelson, Atchley, & Little, 2009) talk on the phone while driving. Although the association between using a cell phone and crashes is undeniable [for recent reviews, see Collet, Guillot, and Petit (2010) and Owsley and McGwin (2010)], the psychological mechanisms remain unclear. And cell phones are just the tip of the iceberg. In response to concerns about the safety of operating phones and other electronic equipment while driving, vehicle manufacturers are now incorporating electronic devices and software that allow hands-free voice control of communication, navigation, and entertainment while driving. Incredibly, even interactions with social media are being promoted! However, the assumption that voice control is safe is based largely upon intuition, and there is good reason to believe that this optimism is misplaced (Strayer et al., 2013).

There have been many experimental demonstrations that speech can have a negative influence on the perceptual and cognitive capacities that are assumed to be critical for safe driving. Most research has concentrated on the slowed reaction times (RTs) that are observed while conversing and driving (e.g. Consiglio, Driscoll, Witte, & Berg, 2003), but some studies have explored how spatial attention is deployed while speaking or listening. Deficiencies in spatial attentional capacity have been associated with an increased risk of collision (Ball, Beard, Roenker, & Miller, 1988; Brabyn, Schneck, Haegerstrom-Portnoy, & Lott, 2001; Coeckelbergh, Cornelissen, Brouwer, & Kooijman, 2004; Owsley et al., 1998; Wickens & McCarley, 2008); and thus, it is of interest to assess how spatial selective attention is modified by speech.

Almost half a century ago, Kahneman, Beatty, and Pollack (1967) showed that talking impairs the deployment of visual attention. Since then, there have been several demonstrations that secondary auditory or visual tasks can reduce the size of the visual field (e.g. Victor, Harbluk, & Engström, 2005; Williams, 1982, 1988), and descriptions like 'tunnel vision' are common. Rantanen and Goldberg (1999) showed that the area of the monocular visual field was reduced to around 92% of normal (monocular: ~60° upward and inward, ~75° downward, and ~110° outward; Harrington & Drake, 1990) in a medium mental workload condition and to about 87% under a heavy mental workload. Their concurrent auditory task required participants to keep track of a continuous sequence of three repeated 1-s tones of different frequencies presented at a 1-s rate in a random order. Using one hand, participants pressed a key when they detected a single small white dot moving inward along one of 24 radials from outside their visual field at a rate of 3°/s. Using the other hand, participants pressed a key when certain conditions were met in the auditory task (e.g. in the high mental workload condition, they had to track two of the three tones and respond to every third instance of the lowest tone and to every second instance of the middle tone). Notably, the RT for the detection of the white dot increased by about 200 ms on average in the high mental workload condition.

However, studies of 'visual tunneling' may not capture the most relevant aspects of how attention is deployed while driving. In Rantanen and Goldberg (1999), the targets appeared against a uniform distractor-free background, and they always moved from the outside inward. Hence, their procedure provided estimates of the outer limits (about 90° laterally) of target detection under a heavy mental workload. However, while driving, peripheral threats must be noticed against a cluttered background of distracting stimuli, and detection is likely only at eccentricities much smaller than 90°.

*Correspondence to: Ian Spence, Department of Psychology, University of Toronto, 100 St. George Street, Toronto, ON, Canada M5S 3G3.
E-mail: ian.spence@utoronto.ca

Furthermore, on the road, real threats generally appear at eccentricities of around 15–30°, and they are dangerous precisely because they are relatively close; more eccentric sudden onset events are unlikely to pose an immediate threat. Thus, while studies of visual tunneling are valuable because they establish the limiting conditions of visibility under varying mental workloads, they are not directly relevant to estimating the likelihood of crashes because the sensory environment encountered when driving in the real world—or even a simulator—is quite different from a featureless environment. It is the ability of the attentional system to *select* a target object among distractors, and to do so quickly, which is most relevant to everyday tasks such as driving.

Spatial *selective* attentional ability may be assessed by determining the size of the attentional visual field (AVF). This is the subarea of the visual field from which information can be extracted at a glance without eye movements (Hassan et al., 2008). The AVF has been called the visual lobe (e.g. Engel, 1977), the useful field of view (e.g. Ball & Owsley, 1993), or the functional field of view (e.g. Pringle, Irwin, Kramer, & Atchley, 2001). Its size and shape correlates with vehicle crashes, falls in seniors, errors in industrial inspection, photo interpretation, and other tasks where critical information is often found in the periphery (Ball et al., 1988; Brabyn et al., 2001; Coeckelbergh et al., 2004; Owsley et al., 1998; Wickens & McCarley, 2008). The AVF differs from the ordinary visual field, which is typically measured by automatic visual perimetry (e.g. Bengtsson, Olsson, Heijl, & Rootzen, 1997), and requires the detection of a target against a uniform background. However, it is generally more difficult to detect a target if the background contains distractors. Although a well-functioning ordinary visual field is undoubtedly important for safe driving, detection in the context of a distracting background is more ecologically relevant, because threatening events occur in visually cluttered surroundings. However, because measurement of the AVF has been implemented in various ways by different researchers, it is difficult to make comparisons without considering the particular method used. Fortunately, almost all methodologies have one element in common: the target appears among distractors rather than against a featureless background. This is a differentiating feature that makes experiments that require the detection of a target among distractors more ecologically relevant to activities such as driving.

On the basis of studies that have investigated how cross-modal tasks affect visual attention, it is not obvious how a concurrent auditory task should influence the deployment of attention. For example, Spence and Read (2003) found that simulated driving was not compromised by a concurrent auditory task, suggesting that participants had prioritized driving and sacrificed performance on the auditory task. On the other hand, Kubose et al. (2006) found that drivers in a simulator were more variable in driving speed and in following an erratically driven vehicle when speaking or listening. However, the criteria in these studies were not measurements of attention. A more recent study (Kunar, Carter, Cohen, & Horowitz, 2008) showed that speech can have an impact on attention. Shadowing a verbal stream had no effect on multiple object tracking (MOT), but both conversation and a word generation task reduced accuracy and slowed responding. Listening and vocalizing did not affect performance; it was the act of *preparing* a vocal response that was harmful. MOT measures *sustained attention* over time, depending on visuospatial working memory (Trick, Mutreja, & Hunt, 2012) and other processes; however, the role that *selective* spatial attention plays in this complex task is unknown. Importantly, MOT does not typically require the deployment of attention across a wide field of view. Selective spatial attention over an extended area may be more relevant to the detection of sudden threats in a cluttered visual environment, as when driving.

Measuring the attentional visual field with UFOV

One of the best predictors of crashes involving motorized vehicles is Ball's UFOV procedure (Visual Awareness Research Group, Inc.), which measures spatial selective attention and other attentional skills. Several studies [see reviews in Clay et al. (2005) and Ball, Owsley, Sloane, Roenker, and Bruni (1993)] have established the importance of being able to detect and identify targets in background clutter in order to avoid crashes. Impairment of spatial selective attentional performance increases the likelihood of collision. Unfortunately, there are relatively few studies that have examined how speech affects the ability to detect targets in the presence of visual distracters, but the available data (e.g. Atchley & Dressel, 2004; Wood et al., 2006) suggest that conversation may reduce the size of the AVF. However, this conclusion is dependent on how the AVF is defined and measured. It is important to consider whether or not the AVF task is a divided-attention task containing a focused-attention component as well as a peripheral target localization component (cf. Richards, Bennett, & Sekuler, 2006). In addition, it is just as important to note whether accuracy is determined using a fixed or variable exposure.

The UFOV procedure implements three tasks to assess visual attention: central identification to assess processing speed; detection of a target in the periphery; and divided attention, which combines these tasks; selective attention is assessed by adding distractors to the peripheral task. Performance on the peripheral detection tasks is assessed by determining the exposure time required to detect a target 75% of the time. Thresholds obtained over a wide field of view are used to establish the size and shape of the AVF (Ball et al., 1988; Atchley & Dressel, 2004). But, as others have pointed out (Richards et al., 2006; Seiple, Szlyk, Yang, & Holopigian, 1996; Sekuler, Bennett, & Mamelak, 2000), this can lead to the potentially controversial conclusion that the AVF shrinks in the presence of concurrent interference (Atchley & Dressel, 2004) or shrinks with age (Ball et al., 1988). Puell and Barrio (2008) also found that UFOV performance deteriorated when participants performed a difficult secondary task involving listening, speaking, and mental arithmetic. Participants took longer to identify a central target and the location of a peripheral target. Again, because of the confounding of accuracy and latency inherent in UFOV, it is not possible to separate these two measures; however, substantially increased latencies were observed when the concurrent task was performed, suggesting that the UFOV and auditory tasks could not be performed independently and in parallel.

Fixed exposure and no central task

Our experiments used a task that was very similar to UFOV, but with a *fixed target exposure time* and *no visual dual task component* (Feng, Spence, & Pratt, 2007; Spence, Yu, Feng, & Marshman, 2009). As we and others (Sekuler et al., 2000; Richards et al., 2006) argue, these differences are crucial. Using a fixed-exposure approach to measuring the accuracy of target localization, we explored how concurrent speech —of various kinds—might modify the detectability of a target in visual clutter across an extended visual field.

Ecological validity

Much previous experimentation has been conducted on-road or in a driving simulator (e.g. Kalkhoff et al., 2009; Strayer et al., 2013), often using live conversation that cannot be replicated exactly across participants or in other experimental variations. Such studies provide a context that is very close to driving in the real world, but they cannot be as tightly controlled and/or as easily replicated by others. In contrast, our experimental designs isolated participants from the irrelevant sources of distraction (whether auditory or not) that are the inevitable companion of on-road and simulator tests. Ultimately, the choice is a trade-off; more realistic conditions sacrifice control for authenticity, and laboratory experiments achieve control at the expense of generalizability to the real world. Our three laboratory experiments included a variety of concurrent speech tasks spanning a wide range of difficulty. Some tasks were probably more challenging than the demands imposed by ordinary conversation.

EXPERIMENT 1: SPEAKING AND LISTENING

We investigated spatial attention under four concurrent speech conditions: (i) answering yes/no questions; (ii) passive listening; (iii) active listening; and (iv) silence. The first condition was intended to simulate a simple but controlled conversation involving both listening and speaking; in the second and third conditions, participants did not speak but only listened; and in the final condition, participants neither listened nor spoke during the AVF task, thus establishing a baseline of performance.

Method

Participants
Undergraduates at the University of Toronto ($N = 22$) participated for course credit. Four participants with overall accuracies below chance were dropped, leaving $N = 8$ men and $N = 10$ women.

Stimuli and apparatus
Participants completed an AVF task by using a computer with a professional quality 21-inch Cathode Ray Tube (CRT) monitor. A head/chin rest controlled the distance from the screen, ensuring accurate visual angles. The stimuli were presented on a uniform light-gray screen. Each trial began with a centered, unfilled fixation square with a dark-gray border (3° × 3°) for 600 ms, subsequently augmented by 24 objects, each uniquely located at an eccentricity of 10°, 20°, or 30°, in one of eight equally spaced directions. The target was a dark-gray-filled square (1.5° × 1.5°) surrounded by an unfilled circle with a dark-gray circumference (3° × 3°) and was located randomly at one of the 24 possible positions. The remaining 23 objects were unfilled distractor squares with dark-gray borders (3° × 3°). The stimulus display was presented for 20 ms, followed by a mask for 600 ms, and then by a response cue (Figure 1). Participants indicated the direction of the target by pressing a key on the number keypad (e.g. '2' for south and '7' for northwest). Participants were instructed to be as quick and accurate as possible.

Procedure
Participants completed the AVF task while (i) answering pre-recorded questions requiring yes-or-no answers (Q&A); (ii) listening to a podcast, knowing they would not be tested on the content (passive listening); (iii) listening to a podcast, knowing they would be tested on the content (active listening); and (iv) without distractions (silence). All pre-recorded material was controlled and presented at normal volume levels (averaging about 60 dB, measured at the chinrest) by the computer via stereo loudspeakers placed on each side of the monitor, slightly to the rear. Thus, the stereo image would appear to be coming from straight ahead, roughly corresponding to the sound of a hands-free phone call coming from the car's speakers, if the audio balance had been adjusted for the driver. Almor (2008) has shown that locating an audio source in front of the participant produces the least interference on a visual task. There were 384 trials of the AVF task in 16 blocks, with four blocks for each speech condition. Blocks 1–4, 5–8, 9–12, and 12–16 each contained the four different speech conditions with the order of presentation determined by the rows of a randomly selected 4 × 4 Latin square so that each speech condition was at a different position in each four-block subset.

Q&A trials. One hundred and ten questions were presented to each participant during the 14 practice and 96 experimental trials. The questions were of the following sort: 'Do you own

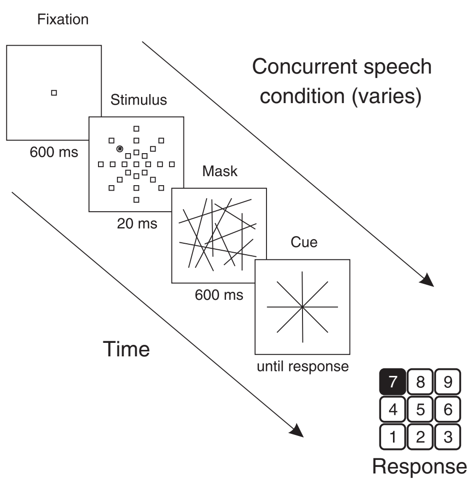

Figure 1. Illustration of a single trial of the attentional visual field task accompanied by concurrent speech

a car?' 'Do you exercise regularly?' 'Are you female?' 'Do you like sports?' 'Have you ever been to Japan?' and so forth.

Podcasts. Participants listened to eight podcasts of less than 5 minutes' duration (four in each of the active-listening and passive-listening conditions) taken from National Public Radio's topic of the day. The assignment of topics to the two conditions was random. The passive-listening topics were violence in New York, the effects of touch on sound, parking garages, and military families. The active-listening topics were shopping for produce, videogames and seniors, high-school football, and cruise ships. After testing, participants answered 20 true–false questions about the podcasts (10 each from the active-listening and passive-listening conditions), as a manipulation check to assess whether participants had paid more attention in the active-listening condition than in the passive-listening condition. The podcasts were presented continuously during the AVF task.

Results and discussion

Premature responses (<100 ms) were presumed to be accidental, and late responses (>6000 ms) were presumed to be guesses; these responses (0.4% of the total number) were ignored in the statistical analysis.

Manipulation check

Participants answered more questions correctly in the active-listening podcast than in the passive-listening podcast (8.2/10 vs. 5.3/10), $F(1, 17) = 25.9$, $p < .0001$, indicating that they had paid more attention in the active-listening condition.

Accuracy

As expected (e.g. Feng et al., 2007), participants were less accurate with increasing eccentricity, $F(2, 34) = 34.2$, $p < .0001$, $\eta_p^2 = .67$. Accuracy did not differ across the four speech conditions, $F(3, 51) = 0.50$, $p = .68$, nor was there an interaction with eccentricity, $F(6, 102) = 0.58$, $p = .75$ (Figure 2, upper panel). There were no significant gender effects.

Reaction time

Speed of responding was affected by the distraction of concurrent speech (Figure 2, lower panel), $F(3, 51) = 20.24$, $p < .0001$, $\eta_p^2 = .54$, and eccentricity, $F(2, 34) = 8.45$, $p = .001$, $\eta_p^2 = .33$. Participants were slower in the Q&A condition than in the other three speech conditions, $F(1, 51) = 57.75$, $p < .0001$, $\eta_p^2 = .53$, which did not differ significantly from each other. There was no difference in RTs between the active-listening and passive listening conditions, and the average of the two listening conditions did not differ from that of the silence condition. There was an interaction between speech condition and eccentricity, $F(6, 102) = 2.95$, $p = .01$, $\eta_p^2 = .15$. Each of the three non-Q&A conditions was slightly slower or faster than the other two, depending on eccentricity (Figure 2, lower panel). As expected (Feng et al., 2007), women were slightly slower than men (610 ms vs. 541 ms), $F(1, 17) = 7.0$, $p < .05$, $\eta_p^2 = .08$, but there were no interactions of gender with other

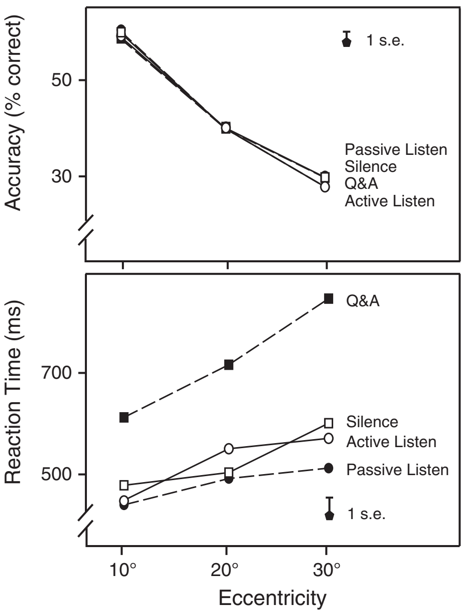

Figure 2. Mean accuracy (percentage of correct responses) and mean reaction time as a function of eccentricity and speech condition in Experiment 1 ($N = 18$). To avoid cluttering the figure, glyphs indicate the average standard error of the means based on pooled within-cell variances. The range of the standard errors varied less than 25% over the 12 experimental conditions

main effects. The analysis of RT was repeated using only trials with correct responses, with essentially the same pattern of results.

Measuring the attentional visual field

Some researchers have reported shrinkage of the AVF with concurrent conversation (e.g. Atchley & Dressel, 2004; Wood et al., 2006); however, our results showed no differences in accuracy among the four speech conditions. This incongruity may be due to how the size and shape of the AVF was determined. Atchley and Dressel (2004) used a commercially available program, UFOV, which assesses accuracy by determining the temporal threshold for the visibility of a target at different locations. Using exposure time as a measure of the detectability of a target confounds detectability with speed of processing. If speech slows responding, as is widely acknowledged, it is not possible to separate latency and accuracy by using a temporal response threshold as a measure of detectability. Moreover, because spatial working memory and spatial selective attention do not seem to be affected by a concurrent verbal task (cf. Postle, D'Esposito, & Corkin, 2005), our results are what would be expected if the three speech conditions had no effect on detectability, relative to the silent condition, across the AVF.

Another problem with the UFOV methodology is that the distribution of attention varies depending on whether participants emphasize the central task or the peripheral task. This creates a competition for attentional resources. If a target is missed at either location, the participant will likely emphasize that location on the next trial. If attention is focused at the central location, this will reduce the attentional intensity in the periphery, possibly shrinking the area of the AVF. The reverse will occur when a peripheral target is missed, spreading the distribution of attention on the next trial. Because, in UFOV, the exposure changes depending on performance, and the participant is able to self-monitor, modification of the attentional distribution is likely because the inter-trial interval is long enough for top-down control to have an effect. If the participant is biased toward the center, the inference will be that the AVF has shrunk. Indeed, using a procedure similar to UFOV, Wood et al. (2006) specifically stressed the importance of the central task (see p. 4647) and analyzed only trials with correct responses on the central task. If participants had tried their best to be accurate on the central task, this would have given the appearance that the AVF had shrunk. Thus, we believe that the 'shrinkage' reported by Atchley and Dressel (2004) and Wood et al. (2006) is likely a consequence of the methods used to measure the AVF, which confound detectability, latency, and response bias.

Our findings that the response time increased in the Q&A condition and that responding in the two listening conditions was no slower than during silence are consonant with those of other studies that have looked at driver RTs while conversing on a cell phone [see Caird, Willness, Steel, and Scialfa (2008) for a meta-analysis of 33 studies]. Experiment 2 was intended to establish *why* responding was slower while answering simple questions.

EXPERIMENT 2: SPEAKING AND THINKING

Experiment 1 showed that answering questions slowed responses on the AVF task. At least two activities in the brain could have been responsible. After listening to a question, the participant had to decide how to answer. Subsequently, the motor actions required for speaking the answer had to be prepared and executed. Either or both of these activities could have contributed to the delay in responding. Experiment 2 was designed to determine whether responding was slowed by the act of (i) preparing the answer; (ii) speaking the prepared answer; or (iii) simply speaking, without the need to think.

Method

Participants
Undergraduates at the University of Toronto participated for course credit. Two participants with overall accuracies below chance were dropped, leaving $N = 17$ men and $N = 17$ women.

Stimuli and apparatus
The same apparatus as in Experiment 1 was used.

Procedure
As in Experiment 1, but the speech conditions were (i) overt Q&A—participants listened to questions, and said yes or no out loud; (ii) covert Q&A—participants listened to questions, decided on yes or no, but did not say the response out loud; (iii) recitation—participants said 'A-B-C-D' repeatedly; or (iv) silence.

Results and discussion

The between-participant factor was gender (male and female). The within-participant factors were eccentricity (10°, 20°, and 30°) and speech condition (overt Q&A, covert Q&A, recitation, and silence). Premature responses (<100 ms) were presumed to be accidental, and late responses (>6000 ms) were presumed to be guesses; these responses (0.5% of the total number) were ignored in the statistical analysis.

Accuracy
Overall accuracy decreased with increasing eccentricity (Figure 3, upper panel), $F(2, 60) = 89.93$, $p < .0001$, $\eta_p^2 = .75$. The four speech conditions did not differ in overall accuracy, and there were no significant interactions involving the three factors. As expected (Feng et al., 2007), men were slightly more accurate than women on average (55% vs. 48%), $F(1, 30) = 4.35$, $p < .05$, $\eta_p^2 = .13$.

Reaction time
Latencies were longer with increasing eccentricity, $F(2, 60) = 18.62$, $p < .0001$, $\eta_p^2 = .38$, and differed among the four speech conditions, $F(3, 90) = 8.65$, $p < .0001$, $\eta_p^2 = .22$, but without interaction (Figure 3, lower panel). As shown by tests based on 1 *df* contrasts, the mean RTs for the two Q&A conditions did not differ significantly, but both were slower than that for silence, $F(1, 90) = 21.79$, $p < .0001$, $\eta_p^2 = .19$, or recitation, $F(1, 90) = 15.67$, $p < .0001$, $\eta_p^2 = .15$, which did not differ from each other. Because overt and covert Q&A did not differ significantly in accuracy or RT, we conclude that preparing the motor response and vocalizing the answer do not require much in the way of additional processing. Similarly, because recitation and silence did not differ significantly, we conclude that the act

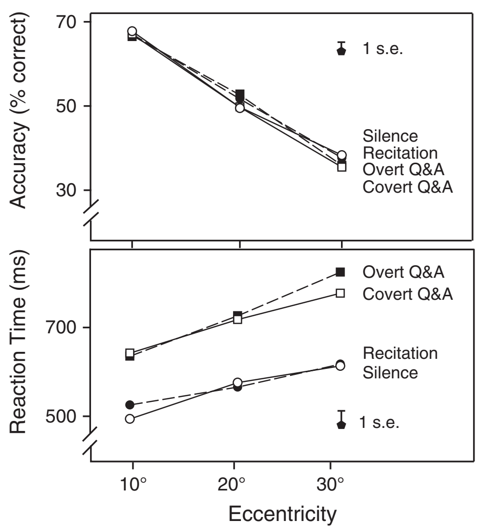

Figure 3. Mean accuracy (percentage of correct responses) and mean reaction time as a function of eccentricity and speech condition in Experiment 2 ($N = 34$). To avoid cluttering the figure, glyphs indicate the average standard error of the means based on pooled within-cell variances. The range of the standard errors varied less than 30% over the 12 experimental conditions

of vocalizing does not require significant additional cognitive resources. It is thinking that slows the response, not speaking. There were no statistically significant effects involving gender.

EXPERIMENT 3: INCREASING THE DIFFICULTY OF THE SPEECH TASK

Experiment 2 showed that preparing answers to questions slowed responses on the AVF task. However, there was no reduction in accuracy whether the answer was spoken or not. It could be argued that the task may have been too easy and that a more demanding task might compromise accuracy as well as RT. Consequently, Experiment 3 introduced more demanding tasks; perhaps even more so than ordinary conversation. We investigated attentional performance under four speech conditions: (i) overt spell checking; (ii) covert spell checking; (iii) generating a word; and (iv) silence.

Method

Participants

Undergraduates at the University of Toronto participated for course credit. One participant failed to complete the experiment, leaving $N = 10$ men and $N = 14$ women.

Stimuli and apparatus

The same apparatus as in Experiment 1 was used. The three distinct word pools were used in Tasks (i), (ii), and (iii): each contained 96 common words that varied between 5 and 10 letters in length, with an equal representation (16 words) at each length. In Tasks (i) and (ii), the spell-checking conditions, half the words were misspelled. When the audio files were prepared for the spell-checking conditions, the order of the words was randomized. The seed words in the generate-a-word condition (Task iii) were also randomized when the audio files were prepared.

Procedure

This was the same as in Experiments 1 and 2, but the speech conditions were (i) overt spell checking—participants listened to a word and its spelling, saying yes or no out loud, depending on whether the spelling was correct; (ii) covert spell checking—participants listened to a word and its spelling but did not say the response out loud; (iii) generating a word—participants were given a word and asked to generate a word beginning with the last letter of the given word (Kunar et al., 2008); and (iv) silence. The spell-checking and generate-a-word items were presented continuously during the AVF task

Spell checking. During the spell-checking conditions, Tasks (i) and (ii), a recorded voice spelled out the letters of a word at about a two-letters-per-second rate while the participant was performing the AVF task. After the word was spelled, the participant had to respond yes or no to the implicit question, ‘Was the spelling correct?’ Half the spellings were correct, and the words were presented in randomized order. In the overt condition, the participants spoke out loud, and in the covert condition, they thought the answer but did not speak. For example, in the overt condition, ‘APPLE is spelled A-P-P-L-E’ could have elicited the correct response, ‘yes’.

Generating a word. Participants heard a recorded word, followed by 5 seconds of silence. During this interval, participants were instructed to generate a word by using the last letter of the word they had just heard as the first letter of the generated word. They were told not to repeat previously generated words. After hearing APPLE, the participants could have generated an appropriate word such as elephant, easy, evergreen, or echo. During this time, the participants continued to perform the trials of the AVF task.

Results and discussion

The between-participant factor was gender (male and female). The within-participant factors were eccentricity (10°, 20°, and 30°) and speech condition (overt check, covert check, generate a word, and silence). Premature responses (<100 ms) were presumed to be accidental, and late responses (>6000 ms) were presumed to be guesses; these responses (1.5% of the total number) were ignored in the statistical analysis.

Accuracy

Overall accuracy decreased with increasing eccentricity (Figure 4, upper panel), $F(2, 44) = 67.97$, $p < .0001$, $\eta^2_p = .76$.

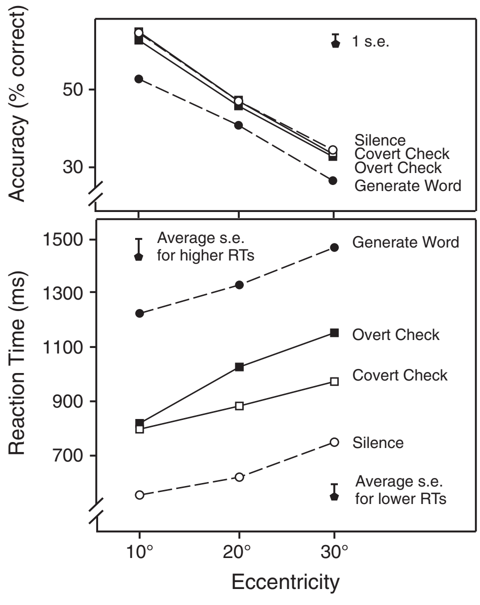

Figure 4. Mean accuracy (percentage of correct responses) and mean reaction time (RT) as a function of eccentricity and speech condition in Experiment 3 ($N = 24$). To avoid cluttering the figure, glyphs indicate the average standard error (s.e.) of the means based on pooled within-cell variances. For accuracy, the range of the s.e.’s varied less than 25% over the 12 experimental conditions. For RT, the glyphs show the average standard errors of the means for short and long RTs, based on pooled within-cell variances in each speech condition. The range of the s.e.’s varied by about 80% over the 12 experimental conditions with the highest s.e.’s at long RTs. The RTs were much longer than in Experiments 1 and 2, except for the silence condition, which did not differ appreciably in the three experiments. Note the compressed scale for RT relative to Figures 2 and 3

The four speech conditions differed in accuracy, $F(3, 66) = 15.70$, $p < .0001$, $\eta_p^2 = .42$, with the generate-a-word condition about 9% less accurate, $F(1, 66) = 44.51$, $p < .0001$, $\eta_p^2 = .40$, than the other three conditions, which did not differ significantly from each other. There were no statistically significant effects involving gender.

Only the generate-a-word condition had an overall effect on accuracy. This reduction in accuracy was about the same at each eccentricity—there was no indication that it was any greater in the extreme periphery. Thus, there was no shrinkage of the AVF, in the sense of a greater drop in accuracy in the periphery. Rather, there was a general loss in accuracy across the AVF. However, whether we interpret that loss in accuracy as shrinkage of the AVF, or as a general loss in accuracy in the AVF, is largely a matter of semantics.

Reaction time

Reaction time was longer with increasing eccentricity, $F(2, 44) = 18.97$, $p < .0001$, $\eta_p^2 = .46$, and differed among the four speech conditions, $F(3, 66) = 29.80$, $p < .0001$, $\eta_p^2 = .58$, but without significant interaction (Figure 4, lower panel). As shown by tests based on 1 *df* contrasts, the mean RTs for the two spell-checking conditions did not differ significantly from each other, but both were slower than that for silence, $F(1, 66) = 19.38$, $p < .0001$, $\eta_p^2 = .23$, and faster than that for generating a word, $F(1, 66) = 42.54$, $p < .0001$, $\eta_p^2 = .39$. Because overt and covert spell checking did not differ significantly in either accuracy or RT, we again conclude that preparing the motor response and speaking the answer do not require much in the way of additional processing.

GENERAL DISCUSSION

Our experiments assessed spatial selective attention in the presence of potentially distracting concurrent activities that involved speech. We used an AVF task with a fixed-target exposure time and no visual dual-task component (Sekuler et al., 2000; Richards et al., 2006) to explore how concurrent speech—of various kinds—might modify the detectability of a target in visual clutter across an extended visual field. For all speech conditions except one (generating a word), the accuracy at each tested eccentricity of the AVF was not substantially altered either by listening to speech or speaking. If shrinkage of the AVF had occurred, the mean accuracies across the speech conditions would have fallen significantly, and accuracies in the periphery would also have fallen. This did not happen, except in the most difficult speech condition (generating a word), where there was a significant drop in accuracy, equivalent to around 20% of base, across all three eccentricities. The clear conclusion is that with both easy and moderately difficult concurrent speech tasks, there was no loss in accuracy, whereas a demanding speech task did have some effect on accuracy. But the primary impact of the more difficult concurrent speech tasks was to delay responding in the spatial attentional task.

Figure 5 summarizes the RT results from our three experiments, showing the deviations in latency of the nine individual speech conditions from baseline (the mean latency for the silence conditions in the three experiments). The nine speech tasks are categorized as easy, moderate, and demanding, relative to the baseline of silence. This is a somewhat arbitrary classification, but it reflects the general increasing trend of difficulty. When the speech task is easy (Q&A and recitation), we observe a substantial impact on RT (averaging about 200 ms, or a 40% increase relative to base) but no change in accuracy. When the speech task is moderately difficult (spell checking), there is no impact on accuracy, but there is a much greater impact on RT (averaging about 400 ms, or an 80% increase relative to base). It is only when the speech task is demanding (generating a word) that there is some impact on accuracy (around 20% relative to base); however, the impact on RT is huge (averaging about 900 ms, or a 180% increase relative to base). Thus, we conclude that preparation for speech (thinking) has little effect on the detection of a target in clutter, except when the speech task is demanding, but there is a large impact on the speed of responding. A similar relationship between braking RT and the complexity of a speech task has been observed in a driving simulator (Strayer et al., 2013, experiment 2)

A processing schema

In Figure 5, we present a processing schema below the charted data. The boxes represent the attentional, working memory, planning, and executive operations that are performed on the two sensory streams (visual and auditory). We do not distinguish attentional and working memory operations because these are largely interchangeable (Feng, Pratt, & Spence, 2012). The sizes of the boxes are not intended to be proportional to specific quantitative values; nor are the boxes intended to suggest independent, standalone resources. There is almost certainly coordination and communication among these resources and other processing resources in the brain. Our schema is a qualitative description that draws on aspects of well-known models (e.g. Pashler, 1994; Wickens, 2002; Wickens & McCarley, 2008).

The letter S represents the processing resource dedicated to visuospatial operations. Similarly, V represents the resource devoted to auditory–verbal operations. These operations are modality specific and generally are not directly concerned with other modalities. However, it is possible that data from one modality (e.g. V, auditory–verbal) might be processed in the resource allocated to another (e.g. S, visuospatial) if the information is relevant to the other modality—see Atchley, Dressel, Jones, Burson, and Marshall (2011), who have shown that the spatial information in a verbal stream seems to be processed by a visuospatial resource in addition to an auditory–verbal resource.

In addition to the modality-specific resources, an amodal resource, A, serves several modalities (Arnell, 2006; Dell'Acqua & Jolicoeur, 2000; Jolicoeur, 1999). This resource is responsible for attentional, working memory, planning, and executive operations that are required by individual modalities, when these operations are not modality specific (e.g., decision making, response selection, and

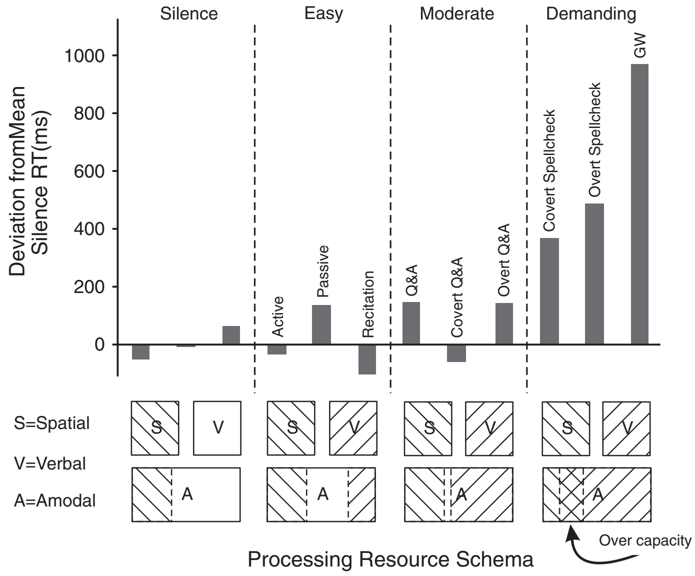

Figure 5. A comparison of latencies in the three experiments grouped by four levels of difficulty: silence [the attentional visual field (AVF) task alone], easy (active or passive listening or meaningless vocalization), moderate (simple question and answer), and demanding (more complex preparation of a response, whether spoken or not). The very demanding generate-a-word condition is abbreviated to GW. The bars show deviations from the mean latency in the control condition (silence). Below the graph, corresponding to the four levels of difficulty, a processing schema shows how attentional and executive resources in the brain might be allocated during the simultaneous performance of the AVF task and the continuous speech task. The resources devoted to visuospatial, auditory–verbal, and amodal processing are labeled S, V, and A, respectively. Because the AVF task is equally difficult in all conditions, the visuospatial resource, A, is always fully occupied. Similarly, with speech, the auditory–verbal resource, V, is likely fully loaded. Both visual attention and speech processing also require an amodal resource, A, for executive processing, planning, response preparation, and processing over and above modality-specific requirements. Although these needs are constant for the AVF task, they increase with the difficulty of the speech task, leading to eventual overload of the amodal resource with more demanding speech tasks

response preparation). Although not shown in Figure 5, it is implicit that all three resources interact with long-term memory systems. Four panels—corresponding to the different categories of difficulty—illustrate the operation of the three processing resources.

Silence

Because the AVF task is difficult (confirmed by accuracy data), it is likely that the visuospatial resource, S, is fully occupied, at least during the interval between the presentation of the stimulus and about 300–600 ms later (Wu et al., 2012). This activity is indicated by hatching in S. There is no speech activity; and thus, the auditory–verbal resource, V, is unoccupied. Because executive processes will be active and because the participant must prepare and make a response, there is activity in the amodal resource (hatching in A).

Easy

The difficulty of the spatial attentional task is unchanged and occupies the same modality-specific and amodal resources. The speech task requires dedicated (V) and amodal (A) resources. The visuospatial resource (S) may also be required depending on content (Atchley et al., 2011), and even the sound source location (Almor, 2008). It does not matter much whether we consider the modality-specific resource (V) to be fully occupied or not. Figure 5 shows the speech task requiring slightly less of the amodal resource, A, than the spatial task. The exact amount is unimportant, but the spatial and speech tasks, in combination, now require more of the amodal resource than in the control condition.

Moderate

The amodal resource is likely to be more heavily occupied with the planning and executive operations associated with the verbal and spatial tasks. These operations will take longer to execute because the majority of the workload of the amodal resource is verbal and hence serial.

Demanding

The generate-a-word task is difficult and may well overload the amodal resource, particularly when performed simultaneously with the spatial task. As shown here, the processing operations required by the verbal resource compete with the operations required by the spatial resource. This implies that spatial functions may no longer be performed without some negative impact on accuracy.

With a sufficiently difficult speech task, the amodal resource is overloaded with a consequent impact on both RT and accuracy in the AVF task. The amodal resource is immune to the demands of easier verbal tasks.

Related research

Our results complement and extend Kunar et al. (2008), but our experiments cover a wider range of speech conditions. Also, Kunar et al. (2008) examined the impact of three speech tasks on MOT, which requires sustained visual attention over time. This differs from the deployment of spatial selective attention, which is almost instantaneous. Kunar et al. (2008) used a verbal shadowing task, conversation with the experimenter, and a word-generation task. Shadowing had no effect, but the conversation and word-generation tasks reduced accuracy—by comparable amounts—and the word generation task slowed responding the most. The shadowing task showed that listening and vocalizing did not affect performance on the MOT task, similar to our finding in Experiment 2. It is the act of preparing the response (thinking) that incurs a penalty in sustained attention (Kunar et al., 2008) or spatial selective attention (our experiments). Our results add significant new information regarding both speed of processing and the ability to deploy attention, almost instantaneously, over a wide field of view. Furthermore, because spatial selective attention has been linked to driving performance on the road and in the simulator [see reviews in Clay et al. (2005) and Ball et al. (1993)], the AVF task that measures an aspect of visual attention may be more relevant to driving. Although MOT may also eventually be shown to be a good predictor of driving competence, its validity remains to be established; we know of only one study that has attempted to establish a relationship between safe driving and MOT performance (Bowers et al., 2011).

Recarte and Nunes (2000, 2003) and Harbluk et al. (2007) have shown reductions in eye movements with concurrent conversational tasks; and these findings might seem to contradict our results. However, their studies addressed different issues in simulated or on-road environments, and their visual tasks assessed the ability to monitor the environment in a continuous fashion. Although reduced eye movements may sometimes be associated with reduced spatial attention, it is important to note that, as in MOT, eye movements reflect continuous ongoing attentional (and other) processes. On the other hand, the AVF task measures the ability to notice a sudden onset target over a visually cluttered wide field of view, and it is this ability that has been shown to be associated with the likelihood of crashes. Nonetheless, the results of Recarte and Nunes (2000, 2003) and Harbluk et al. (2007) are broadly consistent with our findings—concurrent conversational tasks have an impact on visual behavior. Whether the modification of gaze behavior that they observed is correlated with an increased susceptibility to crashes or to the ability to detect threats eccentric to the direction of gaze is unclear.

Like Kunar et al. (2008), we are inclined to interpret our results in terms of a possible bottleneck that occurs when the amodal processing resource is stretched beyond capacity. Only the most complex and difficult task (generating a word) interfered with the accuracy of spatial selective attention in our experiments. If a visuomotor task and an auditory–verbal task are performed in parallel, performance on at least one of the tasks will be worse when the amodal resource is overtaxed. Kunar et al. (2008) favor a cross-modal model of attention where both visual and verbal tasks make use of amodal attentional resources. Our processing schema is similar and may help to explain the dual-task costs that have been observed in some driving studies (e.g. Drews, Pasupathi, & Strayer, 2008; Strayer et al., 2003). Verbal tasks with a spatial component may have an even greater negative impact than purely verbal tasks, presumably because a verbal–spatial task requires access to visual attentional resources in addition to amodal resources (Atchley et al., 2011). Because, in our view, spatial attention and visual working memory share the same processing resources (see Feng et al., 2012, for a review and a model), it is reasonable to expect that tasks that load visual working memory will deplete the resources available for the deployment of spatial attention. Thus, concurrent spatial tasks should modify the AVF, and verbal–spatial tasks should also have a negative impact (Atchley et al., 2011).

Validity of attentional visual field tasks

The deployment of spatial attention during driving differs from what is required in most AVF tasks (e.g. Ball & Owsley, 1993; Engel, 1977; Feng et al., 2007; Hassan et al., 2008; Pringle et al., 2001). First, the driving environment is dynamic—with varying optical flow—whereas AVF tasks are static (no motion). Second, attention is influenced by top-down guidance during driving—threats are much more likely to appear ahead and on the left and right, rather than above and below. And third, context is important—there are fewer threats on a quiet country road than on an urban street at rush hour. Nonetheless, several studies (Ball et al., 1993; Clay et al., 2005) have confirmed the validity of using an AVF task to predict crash risks. Performance on AVF tasks is correlated with on-road and in-simulator driving behaviors: poor performers are at higher risk for crashes. Tasks that require the concurrent preparation of speech further compromise performance. Our conclusion is that the increased risk is primarily a consequence of slowed thinking, but others consider shrinkage of the AVF to be the greater threat.

Atchley and Dressel (2004) and Wood et al. (2006) concluded that conversation reduces the size of the AVF. However, their AVF procedures determined the exposures necessary for a target to be noticed 75% of the time. This threshold is a function of (i) detectability, and/or (ii) processing time, and/or (iii) a bias toward the central task. It is not possible to disentangle these influences. Thus, an increase in the target exposure threshold with increasing eccentricity does not necessarily imply shrinkage of the AVF. We used an AVF task with a constant exposure—and no central identification dual task—thus avoiding the confoundings. Hence, the results of Atchley and Dressel (2004) and Wood et al. (2006) are not necessarily incompatible with our findings—slowed responding can account for their data.

Applications

It is widely assumed by legislators, vehicle manufacturers, and drivers that hands-free speech-only control of information and entertainment devices is much safer than manual intervention (dialing, texting, station changing, route entry, touch screen option selection, etc.). This assumption seems to be based on the intuition that there is no cost to speaking and listening and hence that speech control of devices will not interfere with driving. Our study and other recent researches (e.g., Atchley et al., 2011; Ishigami & Klein, 2009; Laws, 2009; Strayer et al., 2013; Yager, Cooper, & Chrysler, 2012) suggest that this view is mistaken. Although we found that easy to moderately difficult speech conditions did not have much effect on the accuracy with which participants detected targets against a cluttered background, the time taken to respond increased as the speech task became progressively more difficult.

Other factors could have a nonadditive effect on driving. For example, Charlton (2009) and Drews et al. (2008) have shown that conversations with passengers are different from conversations on a phone. Passengers are aware of changing road conditions and the varying demands on the driver, whereas a remote party on a phone cannot be as aware. Passengers can modify their speech behaviors to suit the circumstances, whereas the caller cannot. By becoming silent, passengers can reduce the attentional load on the driver (Charlton, 2009). Interactive devices (e.g. phones and navigation or information systems) that produce speech are even less aware than the remote caller and cannot take the concurrent demands on the driver's attention into account. It is tempting to speculate that, in the future, technology designed to monitor the threat level posed by changing traffic situations could intervene to suspend voice-activated interaction with an information or entertainment device.

Consequences

In our experiments, the speed penalty associated with preparation for speech (thinking) was large (from about 200 to 900 ms), irrespective of whether or not the target was relatively central (10°) or peripheral (20° or 30° from fixation). Because sudden events, such as road hazards during driving, have a lower probability of being detected in the periphery, delays in responding make the production of speech even more dangerous. Even if an external threat is detected, it may not be noticed in time. A vehicle driven at only 50 kph (about 30 mph) will travel approximately 2.8 m (9.2 ft) in 200 ms, 5.6 m (18.4 ft) in 400 ms, and 12.6 m (41.4 ft) in 900 ms (these delays correspond to the demands during the preparation of speech in our experiments). These are not large distances, but a driver who brakes 200, 400, or 900 ms earlier will either avoid the collision or be traveling more slowly if and when the crash occurs. The reduced energy that is dissipated will translate to a lower probability of severe injury or fatality.

Although our experiments showed reduced accuracy on the AVF task only with the most difficult speech task (generating a word), not all individuals would maintain accuracy in most of our experimental conditions. Our participants were college students in their prime and presumably at their attentional, perceptual, and cognitive peak. It is entirely possible—even likely—that a repetition of our experiments with an older population would yield different results. On average, aging drivers perform more poorly on several cognitive tasks than young or middle-aged drivers. Elderly participants might indeed show shrinkage in the AVF with concurrent speech in addition to the expected overall lower accuracy and increased latency.

Nonetheless, for all drivers of all ages, the most important implication of our results is not that speech will necessarily cause drivers to miss visual threats but rather that drivers may fail to notice these sudden events in sufficient time to avoid the crash. Manufacturers and legislators would do well to reconsider the wisdom of the accelerating trend toward voice control of electronic devices in vehicles.

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