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Research Article

Bidirectional Interference Between Simulated Driving and Speaking

Christopher Dromey[a] and Kelsey Simmons[a]

Purpose: This study relied on acoustic measures of connected speech and several indices of driving performance to quantify interference between speaking and simulated driving.
Method: Three groups of 20 younger (ages 20–30 years), middle-age (ages 40–50 years), and older (ages 60–71 years) adults produced monologues and completed a simulated driving task, which involved maintaining a constant speed and lane position on a freeway. Both tasks were completed separately and concurrently.
Results: There were significant divided attention effects, with a reduced speaking time ratio, and increases in vocal intensity, speed variability, and steering wheel adjustments. There was a significant between-subjects age effect for intensity and fundamental frequency as the younger group had less variation with these variables compared to the other age groups across conditions. There was a significant between-subjects age effect for lane position, steering wheel position, and speed as the younger group had less variation in lane position compared to the other 2 groups, and the older group had more variation in speed and steering wheel position compared to the other 2 groups across the experimental conditions.
Conclusion: These findings reveal that divided attention conditions can impact both speech and simulated driving performance. The results also shed some light on the effects of age on speech and driving tasks, although the degree of interference from divided attention did not differ by age.

It is common for people to communicate while they are engaged in other activities, such as walking, working, or driving. Although multitasking in speech is considered normal, the attentional demands of performing two tasks simultaneously can create interference that can cause a decline in performance in one or both tasks (Bailey & Dromey, 2015; Dromey & Bates, 2005). Because everyday conversation is frequently accompanied by other demands on a speaker's attention, both basic and clinical research would benefit from a better understanding of the impact of concurrent tasks on communication. Although the focus of this study was on unimpaired speakers, there may be potential implications for the clinic. Because speaking is common under dual-task conditions, speech performance findings could provide therapists with insight as to how to make the clinic environment more representative of real-life speaking situations, which, in turn, could help patients in the clinic to be more robust when they apply what they learn to their daily lives. Most clinical assessments are conducted in distraction-free environments, where patients' attention can be devoted entirely to the speaking task. It may be profitable to collect additional speech samples when patients are challenged by a concurrent activity in order to more realistically simulate their communication abilities in everyday settings.

Driving is an activity that requires a division of attention in managing lane position, speed, navigation, following distance, and other factors. Over the past two decades, cell phones have increased in popularity, with over 90% of Americans having a cell phone as of 2010 (Strayer, Watson, & Drews, 2010). Consequently, driving while concurrently speaking on a cell phone has become common, with 85% of drivers claiming to engage in cell phone use while driving a vehicle (Strayer et al., 2010). However, because of the competing attentional demands of both driving and conversing, studies have shown a high correlation between accident rates and in-vehicle cell phone use because conversing on a cell phone increases drivers' likelihood of an accident by four times (Beede & Kass, 2006; Cao & Liu, 2013; Strayer & Johnston, 2001; Strayer et al., 2010). In fact, as of 2010, it was estimated that 28% of all vehicle accidents were caused by cell

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phone use (Strayer et al., 2010). Thus, the advent of the cell phone has led to a substantial decline in driver safety.

Because the effect of multitasking on communication is not associated with safety concerns, most research in this area has overlooked the impact of driving on communication. Becic et al. (2010), however, did examine speech measures to determine how driving impacts speaking. They found that, along with conversations interfering with driving performance (i.e., slowed velocity, delayed braking reaction times, but better lane maintenance), driving had a negative impact on speech production, comprehension, and memory; individuals had better recall of stories and more accurate story retelling during the speech-only task compared to the dual-task condition. Accuracy in story recall was also impacted when the driving route was more difficult (e.g., driving through intersections).

Although research on speech measures in dual-task driving situations is limited, multitasking in speech is the norm, not the exception. Thus, several studies have examined how speech is affected by the simultaneous performance of a variety of tasks. For instance, Dromey and Bates (2005) conducted a study to examine the bidirectional interference of speech and nonspeech tasks by having participants repeat *Peter Piper would probably pick apples* while concurrently performing linguistic, cognitive, and visuomotor tasks. The concurrent linguistic task impacted speech performance by increasing both the variability of labial movements and speech intensity. This combined task also impacted nonspeech performance as participants had lower linguistic scores compared to the linguistic-only condition.

In another study, Oomen and Postma (2001) examined the influence of divided attention tasks on disfluencies (filled pauses and repetitions) that are produced in typical speech. The two tasks in the study included a storytelling task and a blind tactile form recognition task, both of which were performed separately and then together in a divided attention condition. The researchers found a decline in performance in both tasks as the participants had more pauses and repetitions (specifically sound/part-word and word repetitions) and poorer performance in the tactile recognition task in the divided attention condition compared to the single-task conditions. Thus, these results lend support to the suggestion that speech tasks can also have an impact on nonspeech task performance.

Over the past few decades, cognitive psychologists have dedicated many research studies to understanding attentional processes, specifically how individuals can concurrently carry out multiple tasks and how much these tasks interfere with each other. Two theories are commonly recognized in the field of divided attention: structural and capacity. Structural theories propose that certain cognitive processes or mental operations are carried out in a sequential order and that, in dual-task conditions, a bottleneck arises as the attentional processes are occupied with the first task before attending to the second task. As a result, performance in the second task becomes delayed (Pashler & Johnston, 1998; Wickens, 1981). Based on this model, Wickens suggested that a bottleneck can arise in any stage of processing and that it is not limited to just one stage or one mental process. In contrast, capacity theories suggest that the brain has limited cognitive resources, and as a result, dual-task performance suffers as one task may demand more attentional resources than the other (Pashler & Johnston, 1998; Strayer et al., 2010; Wickens, 1981).

Because of the cognitive changes associated with aging, some researchers have studied dual-task performance across the adult life span. A consistent finding in previous work is that older adults have poorer performance in concurrent tasks (Bailey & Dromey, 2015; Becic et al., 2010; McDowd & Craik, 1988). Some have suggested that aging in the brain causes either a decline in short-term memory and storage capacity or that the processing resources in older adults are limited in tasks that require a division in attention (McDowd & Craik, 1988).

A decline in dual-task performance in older adults is seen with their driving behaviors. Recent statistics show that driving fatality rates decline from young adult to middle-age years but then increase steadily as the aging process continues. This occurs even though older adults have more driving experience and take fewer risks compared to younger drivers (Strayer & Drews, 2004). Consequently, when cell phone conversations take place in the vehicle, older individuals have to prioritize, because it is difficult for the aging brain to complete both tasks successfully at the same time.

Bailey and Dromey (2015) conducted a study to investigate bidirectional interference between a speech task and nonspeech tasks (linguistic, cognitive, and manual motor), as well as the influence of aging on performance. Their results indicate that task type and age affect speech performance during dual-task conditions and that age can have a significant effect on speech and nonspeech task performance, which supported previous findings. Although these studies investigated the interference arising when simultaneously performing speech and nonspeech tasks, the speech tasks in many of these earlier studies had poor ecological validity because the participants were instructed to repeat the same phrase or sentence many times. These controlled stimuli allowed the researchers to directly compare the same words under different conditions, but the tasks did not reflect everyday speech. Therefore, for the current study, we chose to use a monologue task to better reflect typical communication.

Based on previous research, we hypothesized that individuals would exhibit poorer performance in both driving and speaking for concurrent versus isolated task performance. We also hypothesized that, under divided attention conditions, the older adults would show a greater decline in measures of speech and driving performance compared to younger adults. Acoustic measures of connected speech, including the average and variability of fundamental frequency (F_0) and intensity, as well as the ratio of speaking to pausing time, were used to quantify speech performance. It was reasoned that reduced F_0 and intensity variability in connected speech would reflect a more monotone pattern of expression, which has been reported to reduce intelligibility (Watson & Schlauch, 2008). The proportion of time spent speaking versus pausing was included in this study because interruptions to the flow of speech were anticipated to arise when speakers devoted some of their attention to driving. Measures including speed control, steering wheel turns and position, and lane maintenance were used to quantify driving performance. Previous work (Kubose et al., 2006) has shown that driving speed fluctuates more under divided attention conditions than when driving is the only task. In the driving safety literature, lane position maintenance and steering wheel angle measures have been used to detect the influence of distracting tasks on driving performance (Cao & Liu, 2013). Poorer driving performance would thus be reflected by a reduction in average speed; an increase in the number of steering turns; and an increase in variability of lane maintenance, steering wheel position, and speed.

Method

Participants

Thirty men and 30 women participated in the study, divided evenly into three age groups: young adults (ages 20–30 years, M = 23.10, SD = 2.56), middle-age adults (ages 40–50 years, M = 45.70, SD = 2.81), and older adults (ages 60–71 years, M = 65.60, SD = 3.80). Two additional women in their 60s began the study but discontinued participation because they felt motion sickness when using the driving simulation system. All participants were native speakers of English; had no history of speech, language, or hearing disorders; had normal or corrected-to-normal vision; and had a valid driver's license. Hearing testing was not conducted on the study participants, but each communicated naturally with the experimenters at normal conversational levels. None exhibited any sign of hearing difficulty, such as asking for repetitions or failing to follow the experimenters' prompts. Each participant signed an informed consent document approved by the institutional review board prior to participation in the study.

Equipment

Each participant was seated in a sound booth to provide an optimal environment to make high-quality acoustic recordings and to reduce possible auditory distractions. A microphone headset was used to acquire the participant's speech, which was recorded digitally to a laboratory computer with Audacity software (Version 2.0.6; http://audacity.sourceforge.net/). Prior to data collection, each speaker sustained a vowel while the intensity was measured using a sound level meter (Extech 407736) 50 cm away from the speaker; this allowed the calibration of the audio signal in subsequent analyses. OpenDS software (Version 3.5; https://www.opends.eu/) was used to record driving performance as participants used a Logitech Driving Force GT steering wheel and gas/brake pedal interface on a lab computer to navigate a virtual road. The lab computer had a 24-in. display to provide a view of the simulated driving environment.

Procedure

The participants completed a driving task and a speech task separately in an isolated condition and simultaneously in a divided attention condition. In a pilot study, an unfamiliar user completed the driving task 10 times. Based on the recordings from these 10 trials, it was found that the standard deviation of lane position and speed plateaued around the fifth trial, indicating that 15 min of practice was enough time for users to become familiar with the driving simulator. Therefore, each participant completed five practice trials with the driving simulator prior to recording data to familiarize themselves with the software and to reduce the impact of possible learning effects during the experiment.

Participants were given several minutes to consider monologue topics from an extended list (see Appendix A) and were asked to choose eight topics of interest. Once the experiment began, each participant was presented with a topic that he or she had chosen and was instructed to speak about it. If the participant ran out of things to say, he or she would say "next," and the experimenter presented a new topic for him or her to respond to. The experimenter continued to present topics to the participant until the recording was about 80 s long to ensure it included at least 60 s of the participant's speech for analysis.

The driving task consisted of participants driving a specific course ("Motorway") using the OpenDS software. The duration of the task was approximately 2 min, with a traveling distance of 1,300 m on a freeway. The course consisted of merging onto and later exiting a two-lane freeway. They were instructed to merge onto the freeway as soon as they reasonably could, stay in the center of the right lane after they merged onto the freeway, maintain a speed of 100 km/hr, and take their first exit. The simulation included other vehicles on the freeway, which traveled at a fixed speed of 100 km/hr in order to provide additional distraction. During the divided attention condition, participants drove the simulator while they completed the speech task. The three different conditions were completed in an order that was newly randomized for each individual. The instructions that were given to the participants are listed in Appendix B.

Data Analysis

Speech measures in the isolated condition were compared with the same variables in the divided attention condition to quantify the impact of driving on speaking. Speech recordings were analyzed using the Praat 5.4 software program (Boersma & Weenink, 2014). Experimenter speech, pauses in between topics, and nonspeech behaviors (laughing, coughing, etc.) were trimmed from the recordings prior to analysis. Once trimmed, the middle 60 s of the speech from each condition were used for analysis.

Acoustic measures of connected speech, including patterns of F_0 and intensity, as well as the proportional amount of time participants spoke during their responses, were computed to quantify speech performance. F_0 was measured by taking the mean and standard deviation in the 60-s recording. The F_0 range was adjusted in Praat for individual speakers to avoid tracking errors. The voicing report from this program provided the mean and standard deviation of the F_0. Because the F_0 range differs between males and females, the standard deviation values were converted into semitones using the following equation: STSD = 12/0.301 * log ((Hz mean + Hz *SD* / 2) / (Hz mean – Hz *SD* / 2)). Intensity was also measured by taking the mean and standard deviation of the 60-s recording. To avoid recording the intensity level of pauses or nonspeech sounds, a decibel floor was selected based on the level of intensity of the softest speech sounds in the recording. The intensity listing in Praat was exported as a comma-separated values file. The comma-separated values file was then opened in a custom MATLAB (Version 9.0) application (MathWorks, 2016) to compute the mean and standard deviation of intensity above the selected floor. The speaking time ratio was expressed as a proportion. For example, 1.0 would be all speaking and no pausing, and 0.75 would be 75% speaking and 25% pausing. A custom MATLAB application was used to compute the speaking and pausing ratio. The application normalized the intensity of the recording, and 10% of the normalized maximum root-mean-square amplitude was selected as the threshold. Energy above the threshold was operationally defined as speaking, and segments over 200 ms in length below the threshold were defined as pausing (Dromey, Nissen, Roy, & Merrill, 2008).

Driving measures in the isolated condition were compared with those in the divided attention condition to quantify the impact of speaking on driving. Driving performance was quantified by the mean and standard deviation of participants' speed, variation in lane position, the variation of the steering wheel position, and the number of steering wheel turns, regardless of their size. These measures were computed for the middle 850 m that the driver traveled to avoid the influence of merging onto or exiting the freeway. The OpenDS software created a log file of the vehicle's lane position and speed. These files were imported into a custom MATLAB application for the computation of the dependent variables.

Ten percent of the acoustic and driving data were randomly remeasured for reliability. Across all dependent variables, the average correlation between the original and the remeasured data was .965. The reliability data showed that the only difference during remeasurement could be attributed to the selection of the decibel floor, which may have slightly changed the standard deviation of intensity.

Changes in the dependent measures between the single- and dual-task conditions were tested with SPSS 23 software using a repeated-measures analysis of variance (ANOVA). The within-subject repeating factor was the task condition (isolated vs. concurrent), and between-subjects factors included group (age) and sex. The statistical output displayed results for the main effect of condition on each dependent variable, along with interactions of age group or sex with condition, as well as age group or sex effects that were present across conditions. Post hoc testing (Tukey's honestly significant difference) was used to examine the significant differences between the groups in greater detail.

Results

All results presented below showed significant effects in the ANOVA testing at $p < .05$. The descriptive statistics for the speaking time ratio, average intensity, standard deviation of intensity, and standard deviation of F_0 are shown in Table 1. Because the F_0 differs by about an octave for men and women, the F_0 standard deviation values were converted into semitones to allow a direct comparison of variability for both men and women. The descriptive statistics for lane position variability, average speed, standard deviation of speed, standard deviation of steering wheel position, and number of steering wheel turns are presented in Table 2.

Divided Attention Effects

Speech Variables

The average speaking time ratio differed significantly between the isolated and the divided attention conditions, $F(1, 54) = 6.856$, $p = .011$, $\eta_p^2 = .113$. As seen in Figure 1, the participants' speaking time ratio decreased in the divided attention condition compared to the speaking-only condition. The mean intensity also differed significantly between the conditions, $F(1, 54) = 5.213$, $p = .026$, $\eta_p^2 = .088$. The mean intensity increased in the divided attention condition.

Driving Variables

The standard deviation of speed differed significantly between the two conditions, $F(1, 54) = 7.710$, $p = .008$, $\eta_p^2 = .125$. As shown in Figure 2, the participants' variability in speed increased during the divided attention condition compared to the isolated driving task.

The standard deviation of steering wheel position also differed significantly between the two conditions, $F(1, 54) = 11.157$, $p = .002$, $\eta_p^2 = .171$. The position of the steering wheel varied more in the divided attention condition compared to the driving-only condition.

The number of steering wheel turns or corrections that a participant made also differed significantly between conditions, $F(1, 54) = 98.633$, $p < .001$, $\eta_p^2 = .646$. As shown in Figure 3, the average number of steering wheel adjustments increased in the divided attention condition.

Age Effects

Speech Variables

There was a significant between-subjects effect for the standard deviation of intensity across the age groups, $F(1, 54) = 8.728$, $p = .001$, $\eta_p^2 = .153$. The 20s group had less variation in their intensity compared to the other age

Table 1. Mean and standard deviation of all speech variables by age group and sex for isolated and dual-task conditions.

Speech measures	20s				40s				60s			
	Talking only		Driving and talking		Talking only		Driving and talking		Talking only		Driving and talking	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
STR female	0.79	0.11	0.77	0.13	0.74	0.07	0.74	0.07	0.72	0.07	0.68	0.06
STR male	0.72	0.07	0.73	0.07	0.73	0.07	0.68	0.08	0.75	0.08	0.69	0.07
dB female	65.0	3.4	65.2	3.8	65.3	4.2	65.9	3.8	66.7	3.2	66.8	3.2
dB male	64.3	5.1	64.9	4.9	68.4	4.6	68.4	5.1	67.3	3.9	67.7	4.5
dBv female	5.7	0.9	5.5	0.8	6.8	0.8	6.8	0.6	6.7	0.8	6.9	0.8
dBv male	6.9	1.0	6.4	1.0	7.3	0.4	7.2	0.7	7.0	0.9	7.0	0.9
STSD female	2.6	0.6	2.6	0.7	2.6	0.7	2.7	0.6	2.6	0.9	2.6	0.7
STSD male	2.0	0.6	2.1	0.7	2.9	0.7	3.0	0.7	2.5	0.6	2.5	0.4

Note. STR = speaking time ratio; dB = SPL at 50 cm; dBv = intensity variability (standard deviation) in dB; STSD = semitone standard deviation.

groups. Post hoc testing showed that the 20s group differed significantly compared to the 40s group, $p = .001$, and compared to the 60s group, $p = .004$.

The standard deviation of F_0 in semitones differed across the age groups, $F(2, 54) = 2.919$, $p = .063$, $\eta_p^2 = .098$. Although this between-subjects effect was not statistically significant at $p < .05$, post hoc testing revealed that the 20s group differed significantly from the 40s group, $p = .050$. The variation in F_0 was lower for the 20s group compared to the 40s group, especially in men.

Driving Variables

The ANOVA revealed a significant Condition × Group interaction for lane position deviation, $F(2, 54) = 3.672$, $p = .032$, $\eta_p^2 = .120$. There was a slight decrease in lane deviation during the divided attention condition, with the exception of the women in the 40s group, who had more variability in their lane position during the divided attention condition compared to the other participants. The 20s group deviated from the center of the lane less than the other age groups in both conditions. Between-subjects testing also revealed a significant difference for age group, $F(2, 54) = 7.674$, $p = .001$, $\eta_p^2 = .221$. Post hoc testing revealed that the 20s group had less lane position variability than both the 40s group, $p = .009$, and the 60s group, $p = .002$.

Between-subjects testing revealed that the standard deviation of speed was significantly different by age group, $F(2, 54) = 10.378$, $p < .001$, $\eta_p^2 = .278$. There was an increase in speed variation during the divided attention condition across all ages, but the 60s group had more speed variation in both conditions than the other two groups. Post hoc testing revealed that the 60s group differed significantly from the 20s group, $p < .001$, and the 40s group, $p = .004$.

Between-subjects testing revealed the standard deviation of the steering wheel position to be significantly different across the groups, $F(2, 54) = 5.303$, $p = .008$, $\eta_p^2 = .164$. There was an increase in steering wheel position variation during the divided attention condition across all ages, but the 20s group had less variation in both conditions than the other two groups, and the 60s group had the most variation in both conditions. Post hoc testing showed that the 20s group differed significantly from the 60s group, $p = .006$.

Sex Effects

Speech Variables

Between-subjects testing revealed that the standard deviation of intensity was significantly different by sex, $F(1, 54) = 5.303$, $p = .008$, $\eta_p^2 = .164$. Males across all age groups had more variation in their intensity level compared to females.

Driving Variables

Within-subject testing revealed a significant Condition × Sex interaction for lane position deviation, $F(1, 54) = 3.672$, $p = .008$, $\eta_p^2 = .123$. As stated earlier, the women in the 40s group deviated farther away from the center of the lane compared to the men across all age groups. This was the only driving variable found to be affected by sex.

Discussion

The results provide evidence that dual tasking negatively influenced both speaking and driving. Although there were differences in performance with age, the older participants did not experience greater divided attention interference than the younger individuals, which contrasts with the findings in earlier work (Fraser & Bherer, 2013). It is possible that the tasks in the present experiment were not sufficiently challenging to reveal the type of differences that other authors have attributed to general slowing or to a more cautious approach to multitasking in older individuals (Glass et al., 2000).

Effects of Driving on Speech Performance

As hypothesized, the divided attention condition yielded lower speaking time ratios than the isolated speaking condition for all groups, meaning that they had more pauses in

Table 2. Mean and standard deviation of all driving variables by age group and sex for isolated and dual-task conditions.

	20s				40s				60s			
	Driving only		Talking and driving		Driving only		Talking and driving		Driving only		Talking and driving	
Driving measures	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Lane pos var female	0.27	0.11	0.26	0.08	0.30	0.10	0.51	0.29	0.35	0.09	0.35	0.11
Lane pos var male	0.25	0.08	0.20	0.06	0.33	0.09	0.29	0.11	0.44	0.22	0.38	0.19
Mean speed female	100.3	1.8	100.7	1.1	99.5	1.8	99.7	3.0	99.6	2.6	98.2	4.8
Mean speed male	99.3	1.6	100.3	3.4	99.1	2.2	99.2	3.6	99.1	2.8	98.3	3.9
Speed var female	2.9	1.8	5.4	2.9	4.7	1.6	4.9	1.9	5.8	1.6	6.5	2.2
Speed var male	3.2	1.4	4.3	2.3	4.3	2.1	4.3	1.8	6.3	3.1	7.1	2.7
Steer var female	0.0013	0.0007	0.0018	0.0006	0.002	0.0008	0.0026	0.0012	0.0021	0.0016	0.0037	0.0042
Steer var male	0.0012	0.0006	0.0015	0.0007	0.0014	0.0011	0.002	0.002	0.0026	0.0013	0.0036	0.0024
Steer turns female	26.3	10.5	42.3	16.7	31.2	10.0	46.4	12.9	29.4	15.6	46.6	26.2
Steer turns male	23.1	5.4	42.0	11.2	21.1	8.2	33.9	10.6	33.3	11.8	56.6	29.2

Note. Pos var = position variability in meters; speed = in km/hr; speed var = standard deviation of speed in km/hr; steer var = steering wheel position variability in arbitrary units; steer turns = count of steering wheel adjustments.

Figure 1. Mean and standard deviation of speaking time ratio for all participants in the isolated and dual-task conditions.

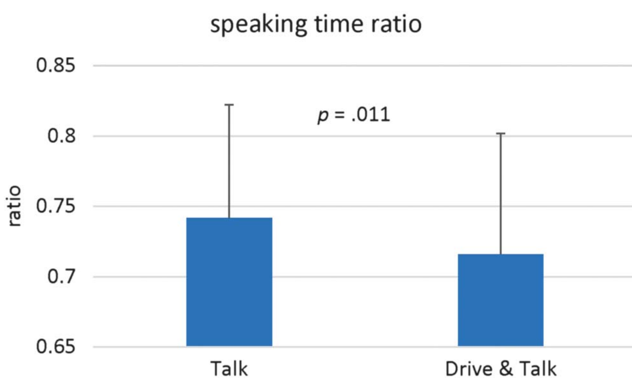
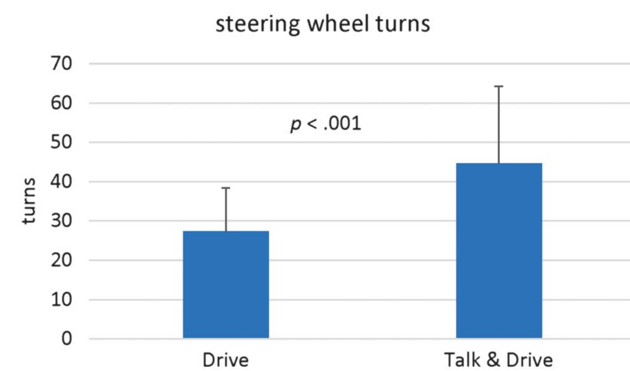
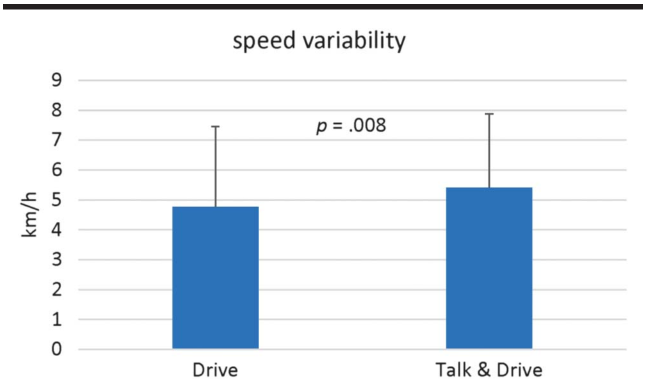


Figure 3. Mean and standard deviation of the count of steering wheel turns for all participants in the isolated and dual-task conditions.



their speech when they were driving at the same time. This could be a result of the limited attentional resources available for the individual to process what to say next due to the cognitive demands of the driving task. This is congruent with limited capacity theories of divided attention (Pashler & Johnston, 1998). Because the tasks in this study were performed concurrently rather than sequentially, the design was more suited to examining an effect that could be attributed to limitations in capacity. The increased pausing in the dual-task condition could also potentially be explained by Wickens' time-sharing model, namely that the alternation of attention between the two tasks was not quite fast enough and thus performance on the speech task declined (Wickens, 1981). In the present experiment, such switching may have been sufficiently rapid to allow the performance of both tasks without severe interference. Researchers who have focused more explicitly on time-sharing theories have often used paradigms where participants are given a series of tasks to perform in a rapid sequence, and performance is measured in part by the latencies involved in switching from one task to the next (Fraser & Bherer, 2013). This approach would be poorly suited to a speaking and driving experiment. However, it cannot be ruled out that

Figure 2. Mean and standard deviation of driving speed variability for all participants in the isolated and dual-task conditions.



the participants in this study were able to shift their attention rapidly between speaking and driving while both tasks were completed simultaneously. Because we did not instruct our participants to prioritize either speaking or driving, individuals may have applied their own strategies for managing the competing tasks.

Because the driving task in this study only required simple lane position and speed control, it was not possible to determine whether the location and duration of the pauses had a direct connection to driving events. A more sophisticated driving task involving a simulation of city driving conditions would allow an analysis of the timing of pauses relative to challenges such as negotiating intersections, avoiding collisions, and responding to other unexpected events. This type of study might also uncover evidence of a time-sharing strategy if the pauses were found to align with instances where increased attention to driving is required.

Contrary to our predictions, the divided attention condition resulted in an increase in the average intensity of speech compared to the isolated condition. In other words, across all ages and for both sexes, participants spoke more loudly when they were driving. Similar findings were reported in previous studies of concurrent speech and manual motor tasks (Dromey & Bates, 2005). It could be speculated that an overall increase in effort in response to the dual-task demands led the participants to speak more loudly. MacPherson, Abur, and Stepp (2017) reported a nonsignificant trend of higher sound pressure level during a more cognitively demanding speaking condition, along with significant increases in variables reflecting autonomic arousal. Higher arousal from the dual-task challenge may have led to the intensity increases in this study.

Modulation of intensity and F_0 creates intonation patterns in natural speech to convey meaning and emotion. Reduced variability in intensity and F_0 can result in less natural speech and has been associated with decreased intelligibility in dysarthria (Bunton, Kent, Kent, & Duffy, 2001). Between-subjects tests revealed that the standard deviation of intensity differed significantly by group and sex. Contrary to our hypothesis, post hoc results revealed significant differences between the 20s group and the other groups; the 20s group had less variation in intensity across both conditions compared to other age groups. It was also found that the men had greater intensity variability across both conditions compared to the women. The reason for these findings is unclear, although previous work has reported prosodic differences between the sexes in the production of declarative and interrogatives utterances (Fitzsimons, Sheahan, & Staunton, 2001).

Effects of Speaking on Driving Performance

As predicted, the standard deviation of speed for all participants increased in the dual-task condition. These results differ from those reported in some previous studies (Becic et al., 2010). The dual-task condition also resulted in a slight increase in average speed for the two younger groups and a slight decrease for the 60s group, although these results were not statistically significant. These trends support the findings from previous studies reporting that participants drove faster when performing speech production and comprehension tasks, conversing on a phone, or participating in an emotional conversation (Beede & Kass, 2006; Dula, Martin, Fox, & Leonard, 2011; Kubose et al., 2006). Dula et al. (2011), however, found that there was no difference in speed maintenance between a mundane conversation condition and the isolated driving task. Between-subjects tests also revealed that the 60s group had greater variability in their speed than the younger groups. This result could be attributed to the effects of the aging brain as divided attention performance declines in older populations (McDowd & Craik, 1988). Strayer and Drews (2004), however, found that age was not a significant factor in driving performance when concurrently speaking on a hands-free cell phone. The authors found different driving behaviors between the older and younger adults (e.g., following distance from the lead car, braking response time) but did not find any significant differences in overall driving performance.

The standard deviation of steering wheel position and the number of steering wheel turns both increased in the divided attention condition. These results differ from those in a previous study, which reported that steering wheel control was not affected during dual-task conditions (Cao & Liu, 2013). An increase in the number of steering wheel adjustments may have allowed better overall lane position maintenance. The standard deviation of steering wheel position increased for the divided attention condition for all ages, but the 20s group had the least amount of variation in both conditions, and the 60s group had the most. Post hoc testing showed this difference to be statistically significant. It is possible that the 20s group had more recent and extensive experience with video games compared to the 60s group. Alternatively, the older individuals may have experienced a decline in their visual–spatial processing abilities (Owsley et al., 1998).

The standard deviation of lane position did not change in the dual-task condition as a significant main effect in the ANOVA, but it was found to interact significantly with age and sex because of the 40s female group. This is because four of the 10 women merged late onto the freeway in the concurrent speaking condition. As a consequence, they were still merging when the lane position measurements had started. Although these errors skewed the data, the same participants did not merge late in the driving-only condition. Thus, the distracting nature of the divided attention condition may have caused the women to merge late and increase their standard deviation of lane position. Post hoc testing also revealed that the 20s group was less variable in lane position than the older individuals. Although the older groups would have had more years of driving experience, it is possible that these findings were due to age-related declines in neuromotor function (Seidler et al., 2010).

Limitations of the Current Study and Directions for Future Research

Several of the limitations in this study were related to the driving simulator setup, including the OpenDS software and the consumer-grade hardware. The software version that was used in this study offered few tasks that could provide quantifiable driving data. The Motorway task that was used only measured driving performance of the middle 850 m of the straight-line course. The course did not involve any turns, stops, or other driving scenarios that may have required more attention. Although the driving task did require some attention, future studies could explore more complex driving tasks to increase the level of attention required of the participants.

The steering wheel was very sensitive when participants made turns, which may have contributed to the motion sickness reported by two of the women in the 60s group, as well as dizziness reported by two other women in the 60s group. In fact, two additional women in the 60s group (not included in the participants reported here) had to withdraw from participation due to feelings of motion sickness. Future studies could explore programming the steering to be less sensitive or using a better equipped simulator to eliminate these effects and to make the driving task more realistic.

In addition to the driving task limitations, a different set of monologue topics was selected by each participant for the speech task. It is possible that some topics were easier to speak about than others. Thus, the topics that were more difficult to speak about may have required more processing or attention, which may have resulted in more pauses, changes in intensity or variation of intensity, or decreased F_0 variation. It is also possible that some topics could elicit a more emotional response from speakers, which has the potential to influence intensity and F_0 variability. However, because the task sequence was randomized across speakers, a systematic influence of topic choice seems unlikely; instead any effects would probably have been equally distributed across speakers and conditions.

Audiometric assessment was not conducted on the participants in this study. However, all conversed easily with the experimenters at natural conversational levels. It is possible that differences in hearing acuity could have led to differences in speech patterns and also the extent to which speech may have been affected in the dual-task condition. In future work, it would be valuable to obtain audiometric data to understand the potential influence of hearing status on performance. Also, the participants were not recruited on the basis of handedness. In a previous study (Dromey & Shim, 2008), only right-handed participants were included because that experiment compared dominant and nondominant hand performance on a fine motor task. In this study, the speaking and driving tasks did not involve such comparisons, and we reasoned that a variety of factors, including handedness, height, weight, vital capacity, second-language experience, and musical ability, would likely be distributed randomly across participants and thus not exert a systematic effect on the dependent measures in the study.

This study relied on rather general acoustic metrics to reflect performance during spontaneous monologue production. We chose to sacrifice the level of experimental control that would be possible with segmental measures of repeated phrases under the different conditions in order to maximize the ecological validity through an open-ended speaking task. Future work to investigate possible changes in the sentence length, semantics, and linguistic complexity would allow further insights into the impact of distraction on spoken language.

Conclusion

These findings may have potential clinical implications for the treatment of patients with communication disorders. The setting and format of therapy sessions typically eliminate distractions. Although this may provide patients with an optimal environment to learn and practice their communication goals, it may limit the extent to which their skills will generalize because speaking in everyday settings includes distractions. The findings of the current study thus suggest that divided attention conditions could be incorporated into assessment and treatment plans to more realistically simulate everyday communication.

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Appendix A (p. 1 of 2)

Monologue Topics

Personal

- Would you quit if your values did not match your employer's?
- If you could be rich, famous, or influential, which would you choose and why?
- How would you define faith?
- How do you define wealth?
- Do you believe people make happiness or stumble across it?
- Which is more important, talent or hard work?
- Are you an introvert or an extrovert? What are the pros and cons of each?

Media

- Are antidrug and antismoking ads effective?
- What video game would you like to redesign?
- Do social media campaigns stimulate real change?
- Should people be allowed to obscure their identities online?
- Is TV stronger than ever, or becoming obsolete?
- What ideas do you have for a reality show?
- What is your opinion about violence on television and in video games?
- What artists of today are destined for the Rock and Roll Hall of Fame?

Generations

- What is the difference between your generation and my generation and why?
- Is your generation more self-centered than earlier generations?
- Are young people generally more selfish than their parents and grandparents?
- How will our current culture be remembered in history books?
- Do children today have good manners?
- Does age make you more aware of and caring for others?
- Should adults try to teach young people lessons or should they leave them alone to find out about things themselves?
- Should parents continue to financially support their children after the children are 18?
- Is modern culture ruining childhood?

Appendix A (p. 2 of 2)

Monologue Topics

Local Issues

- If you could expand the Trax system, what changes would you make?
- What do you see as the pros and cons of the proposed rebuilding of the Salt Lake Airport?
- Is it important to shop at locally owned businesses?
- What could be done about Salt Lake's homeless population?
- What are the pros and cons of the Sugarhouse trolley?

Social

- What has caused the obesity epidemic in America?
- Should people get plastic surgery?
- Should rich people have to pay more taxes?
- What is your opinion about cloning?
- What are the ethical implications of eating meat?
- Are children of illegal immigrants entitled to a public education?
- Should welfare recipients be required to take drug tests?
- If you were a philanthropist, what groups would you finance and why?
- When should juvenile offenders receive life sentences?
- Should women soldiers be in combat?
- What is your opinion about legalizing marijuana?
- Are we losing the art of listening?
- Do attractive people have advantages others don't?
- What are the most important changes in the world since the year 2000?

Education and Related

- Is online learning as good as face-to-face learning?
- How necessary is a college education?
- Should cash-strapped schools cut arts education?
- Should guns be permitted on college campuses?
- What do you think about home-schooling versus public versus private school?
- How would you make over the university system?
- Whose fault is it if a child is failing in school?
- Should parents/grandparents give cash rewards to kids for good test scores?
- Should university students be required to take drug tests?
- Should junk foods and soda-pop be sold in elementary school or high school vending machines?
- How well do you think standardized tests measure people's abilities?

Appendix B

Instructions to Participants

Practice Drives

- (Countryside course): Feel free to drive around. The goal of this is to help you get used to the simulator. So, take a few minutes and drive around on this course.
- (Motorway course): We will now have you drive around on this course. This is the course we will be using later on. Take the first exit on the freeway. Continue down the road and you will be back to the beginning of the course. We will let you continue to do this for a few minutes.
- (Motorway course): Continue driving on this course, but watch your speed more closely. Try to go around 100 km/h.
- (Motorway course): We will have you keep driving this course. In addition to your speed, watch your lane more closely. We will have you drive this course for a few more minutes.

Topic Selection

- Here are a few topics that we will have you talk about during the study. Go ahead and look over these and just put a checkmark by any of the ones that are of interest to you or that you wouldn't mind talking about.

Driving Task

- You will enter onto a freeway that is two lanes across. We ask that you stay in the right lane and maintain a constant speed of 100 km/hr.
- There will be other cars in front of you and behind you on the freeway. They are set at a constant speed, so avoid running into them.
- Please avoid touching anything besides the steering wheel with your hands, and the gas and brake pedals with your feet. Avoid touching any of the other buttons on the controller.
- Take the first exit you see to exit the freeway.
- Start driving as soon as the simulation is loaded. Once the simulation begins, you will need to begin driving the car to merge onto the highway.

Monologue Task

- For this speech task, we will have you talk about a certain topic for approximately 1 min.
- We will place a headset microphone on you to record your responses.

Divided Attention Condition

- We will now have you talk about one of the topics that you selected while also driving the simulation.
- Try to drive and talk as you normally would.