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The Effect of Age on Speech Motor Performance During Divided Attention

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ABSTRACT

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The present study examined the divided attention effects of three non-speech tasks on concurrent speech motor performance. These tasks targeted linguistic, cognitive, and manual motor activity. Participants included 60 healthy adults separated into three different age groups of twenty participants each: college-age (20s), middle-aged (40s), and older adults (60s). Each participant completed a speech task once in isolation and once concurrently with each of the three non-speech tasks: a semantic decision task, a quantitative comparison task, and a manual motor task. The non-speech tasks were also performed in isolation. The speech task involved repeating a target phrase each time a beep sounded, for a total of fourteen repetitions. Dependent measures for speech were derived from lip kinematic recordings from a head-mounted strain gauge system. Dependent measures for the other tasks included timed response counts and accuracy rates. Results indicated significant divided attention effects, impacting speech and non-speech measures in the linguistic and cognitive conditions, and impacting speech measures in the manual motor condition. A significant age effect for utterance duration was also found, as well as a divided attention interaction with age for cognitive task accuracy. The results add to what is known about bidirectional interference between speech and other concurrent tasks, as well as age effects on speech motor control.

Keywords: age, bidirectional interference, divided attention, speech kinematics, older adults, speech motor control, young adults

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Introduction

Speech is one of the most sophisticated feats of fine motor performance. In typical individuals, the neuromotor control underlying these movements is highly adaptable to changes. People speak on a daily basis in a variety of circumstances, and their speech seldom changes, even in the presence of distractions or while they are performing other tasks. However, research has shown that speech production can be affected in subtle ways by the concurrent performance of other tasks, even in individuals without speech disorders. Certain aspects of speech are measurably affected when a person speaks at the same time they are doing something else (Dromey & Bates, 2005; Dromey & Benson, 2003; Dromey & Shim, 2008). As with other activities, when a person speaks while they are performing another task, one or both tasks can be affected. This may cause a decline in performance known as *interference*.

Cognitive psychology models of divided attention have been developed to explain why performance of one or both tasks declines in a dual-task paradigm. An early theory of divided attention processing discussed by Kahneman (1973) and Norman and Bobrow (1975) suggested that individuals have a limited capacity of resources for attention, and when two concurrent tasks are attempted, the two share these resources. If there are insufficient resources for both tasks, then one or both tasks receives a lower level of attention than it requires, causing interference. Later, Navon and Gopher (1979) suggested that a single, central pool might not be an adequate explanation. They proposed that instead of one central pool of attention resources, individuals have multiple pools for the multiple types of cognitive processes. This theory was developed to explain why the types of tasks performed in dual-task experiments lead to varying levels of interference. Navon and Gopher cite the example of Brooks (1968), who showed that two concurrent visual tasks interfered more than a visual task and a verbal task. The same was true for two concurrent verbal tasks. Research reported by Kinsbourne and Hicks (1978) summarized the differences in interference between various pairs of tasks and attributed these differences to the physical distances between the cortical areas responsible for processing those tasks. Although this theory, known as the functional distance hypothesis, is useful for explaining differences in interference levels for a wide variety of tasks within dual-task paradigms, application of the theory to speech has not yielded convincing supportive evidence. Dromey and Shim (2008) found that although some hemisphere-specific interference for speech was observed for right-handers performing a manual motor task, it was difficult to interpret it as evidence for the functional distance hypothesis. It could be speculated that the equivocal results were found because dominant hand performance required less attentional processing, and because motor and language functions may not be completely lateralized at the cortical level. Another theory of divided attention addresses the order of processing of the tasks in a dual-task paradigm. Wickens (1981) suggested the possibility that processing of two concurrent tasks was alternated between one and the other. He proposed that if the switching were done quickly and smoothly enough, the results would be virtually indistinguishable from capacity models. Although these theories have been studied for decades, there is still much to be learned about the cognitive mechanisms of dividing attention.

Researchers have discussed at length how divided attention affects a number of processes, including gait (Camicioli, Howieson, Lehman, & Kaye, 1997; Chen et al., 1996), manual tasks (Dromey & Bates, 2005; Dromey & Shim, 2008; Talland, 1962), postural stability (Dromey et al., 2010), memory (Naveh-Benjamin, Guez, & Marom, 2003; Troyer & Craik, 2000), and speech fluency (Oomen & Postma, 2001). Previous work has also shown that speech motor performance may be affected during conditions of divided attention. Several concurrent non-speech tasks, including cognitive, linguistic, and manual motor tasks, have all been shown to affect speech motor performance. Dromey and Benson (2003) reported the effects of divided attention in college age adults. They used lip kinematic measures to evaluate the effect of a manual motor task on a concurrently performed speech task. In their dual task condition, Dromey and Benson found reduced lip displacement and velocity, suggesting that the participants were undershooting their articulation while performing a manual motor, linguistic, or cognitive task. They also computed the spatiotemporal index (STI) by time- and amplitude-normalizing ten displacement waveforms for each condition, and calculating the sum of the displacement standard deviations at 50 equally spaced points throughout the movement record. This provided a measure of the variability across multiple repetitions of the same utterance. Dromey and Benson found that linguistic and cognitive distractor tasks increased the STI for the lower lip. This indicated that participants were less consistent in their lower lip movements while they were performing linguistic and cognitive tasks.

In a follow-up study, Dromey and Bates (2005) examined not only how the speech motor performance of an individual changed when attention was diverted to various distractor tasks, but also how the individual’s performance on the secondary task changed while they were speaking. In other words, they examined bi-directional interference involving speech and other tasks. The quantitative measurement of both tasks in a dual-task paradigm revealed that certain combinations of tasks caused interference, whereas others did not. They found that concurrent performance of a linguistic task led to an increased lower lip STI, as well as a decrease in performance for the linguistic task. However, they also found that although a visuomotor task led to a decrease in lower lip and jaw displacement, participants did not experience a significant decline in performance of the visuomotor task. This may have been due to a lack of difficulty in the visuomotor task, or to learned automaticity of the speech task. Later, Dromey and Shim (2008) also found interference between speech and a manual motor task. The interference effect was further demonstrated by Dromey et al. (2010), who found that individuals with Parkinson's disease experienced bidirectional interference between concurrent postural stability and speech task performance; the interference negatively affected the postural stability task as well as diphthong duration in a concurrently performed speech task.

Divided attention interference has also been observed in older individuals, where it is usually present to a greater degree than in younger adults. Although a general multitasking mechanism that decays with age has not been clearly identified, many studies have found specific age-related multitasking deficits. Talland (1962) found that middle age and elderly men were slower at performing two separate motor tasks (one with each hand) than college age men. Chen et al. (1996) found that divided attention negatively impacted older adults more than younger adults during an obstacle-avoidance walking task. An age-related increase in interference has also been demonstrated in speech motor performance. Dromey et al. (2010) showed that speaking affected gross motor performance, resulting in reduced heel height in a concurrent postural stability task in a group of older adults (age, M = 70.5 years). Camicioli, Oken, Sexton, Kaye, and Nutt (1998) also found that speech and gross motor tasks can create interference in healthy older adults (age, M = 71.7 years); they reported that performing a verbal fluency task reduced the number of steps taken by all participants, with and without Parkinson's disease. In another study, Holmes, Jenkins, Johnson, Adams, and Spaulding (2010) found that when speaking distractor tasks were relatively complex, their participants, both with and without Parkinson's disease, experienced measurable changes in postural stability. However, the latter two studies did not compare performance on the same tasks with a younger group.

One reason divided attention disproportionately affects older individuals could be the aging of the motor control system; it is well known that with increasing age the ability to initiate and carry out motor functions is gradually impaired. This is primarily due to reduced strength, peripheral sensation, balance, and coordination of multi-joint movements, and increased reaction time (Ketcham, Dounskaia, & Stelmach, 2004; Menz, Lord, & Fitzpatrick, 2003). This decline in motor control extends to the movements critical to speech. Ballard, Robin, Woodworth, and Zimba (2001) found that children and older adults were less able than young adults to perform a non-speech oral visuomotor task and were less accurate in matching biofeedback of the amplitude of the movement of their lower lip, jaw, or fundamental frequency (a function of the larynx), with the movement of a visual target. This general decline in motor performance, including non-speech motor performance, could be seen as a motor task requiring a larger share of attentional resources in older adults than the same task performed by younger adults. Or, from the perspective of another divided attention theory, older adults may be switching between tasks more slowly than younger adults.

Research examining how age influences divided attention for speech has so far been limited (Dromey et al., 2010). Based on the available related research, it could be hypothesized that age negatively impacts speech motor control in divided attention conditions. Comparison of different age groups for both single-task and divided attention conditions will increase our understanding of the aging brain. Craik (1977) suggested that the effects of aging on a memory encoding task could be mimicked by divided attention conditions. As memory encoding and speech motor control both require attentional resources, this suggests that young participants might perform speech motor tasks in divided attention conditions similarly to older adults in single-task conditions.

It is anticipated that in divided attention conditions, all participants will experience reduced speech motor performance when compared to single task conditions, and this will be shown by a higher STI and lower values of lip and jaw displacement and velocity. It is hypothesized that older adults will be affected by divided attention conditions to a greater degree than younger adults, and this will be shown by a greater decrease in speech motor performance than that observed in younger adults when single task and divided attention conditions are compared. This means that younger adults should demonstrate the most consistent speech motor control during divided attention conditions, as shown by a lower STI and higher values of lip and jaw displacement and velocity. It is also hypothesized that bidirectional interference will affect older adults to a greater degree than younger adults, leading to comparatively greater declines in non-speech performance during divided attention conditions. Observing interference of speech on non-speech performance will give insight into how speech shares attentional resources, and whether this sharing changes with age. It is anticipated that bidirectional interference will moderately affect the motor speech and non-speech task performance of middle-aged adults, giving insight into the age at which speech motor control becomes more susceptible to divided attention conditions.

Method

Participants

Thirty male and 30 female adults participated in the study. Each of three age groups was divided evenly into ten male and ten female participants. The age groups included college-age adults (ages 20-28, *M* = 22.95, *SD* = 2.35), middle-aged adults (ages 40-50, *M* = 45.60, *SD* = 3.47), and older adults (ages 58-70, *M* = 63.20, *SD* = 3.55) participated in the study. All participants were native speakers of English and signed informed consent documents approved by the Institutional Review Board prior to participation in the study.

Equipment

Each participant was seated in a single-walled sound booth to ensure optimal recordings and reduce potential auditory distractions. A head mounted strain gauge system was used to measure the movements of each participant's lips and jaw. Cantilever beams were attached to the skin using double-sided tape at the midpoint of the vermillion border of the upper and lower lips and under the chin. These three kinematic signals were digitized using a Windaq 720 (DATAQ Instruments) analog/digital converter at 1 kHz. A microphone was attached to the strain gauge system in order to record the participant's speech, which was digitized at 25 kHz after being low-pass filtered (Frequency Devices 9002) at 12 kHz. A laptop computer located outside the window of the sound booth and a computer mouse located inside the sound booth were used for the cognitive and linguistic tasks.

Procedures

All participants completed four types of task: a speech motor task, a manual motor task, a cognitive task, and a linguistic task. Each task was completed once by itself in an isolated condition, and the speech motor task was performed concurrently with each of the non-speech tasks in a divided attention condition. Each participant completed a series of practice trials of all tasks before the experimental trials to mitigate any possible practice effects. Order of the tasks and conditions was counterbalanced across participants. The total time to complete the tasks, including equipment setup and training, was about 45 minutes per participant.

Tasks

The speech motor task consisted of speaking the phrase *I saw Patrick pull a wagon packed with apples* every time they heard a tone. The tone was repeated at regular intervals of about four seconds. The vowels and consonants in this sentence require large jaw and lip movements and were chosen to facilitate signal segmentation during analysis.

The manual motor task consisted of the Purdue Pegboard Test (Tiffin, 1948) performed with both hands. Manual motor performance was quantified as the number of pegs placed in 60 seconds. During the divided attention condition, participants placed pegs in the pegboard while they completed the speech motor task.

For the cognitive task, participants performed a quantity comparison activity. This involved participants viewing a computer screen that showed two numerical values in fraction notation with an equal sign in between them; the participants used a computer mouse to select one button if the quantity comparison was correct (for example, *2/3 = 4/6*) or another button if the quantity comparison was not correct (for example, *1/4 = 4/8*). The participants were given 60 seconds to categorize as many quantity comparisons as possible. During the divided attention condition, participants completed the quantity comparison task while they were repeating the target sentence.

For the linguistic task, participants performed a semantic decision activity similar to the one described in a neuroimaging study by Müller, Kleinhans, and Courchesne (2003). Their semantic decision task involved participants viewing a computer screen that showed two words, a noun and a verb, and responding whether or not the two were semantically related. For example, *joke/laughing* made a semantic pair in the present study, while *dough/interviewing* did not make a semantic pair. The participants were given 60 seconds to categorize as many pairs of words as possible. During the divided attention condition, participants completed the semantic decision task while they were repeating the target sentence.

Data Analysis

Lip and jaw kinematic measurements were taken from ten tokens of the target phrase in each of the conditions: the speech-only and the three divided attention conditions. These tokens were judged as perceptually correct by at least one listener. The signals were segmented based on consistent markers in the velocity record, as shown in the lower chart of Figure 1.

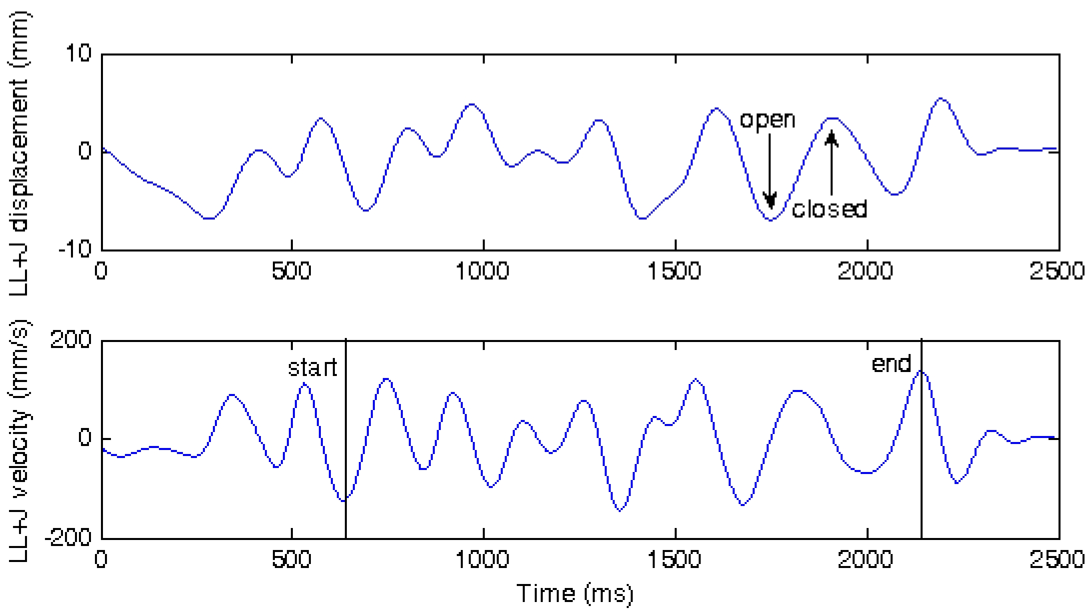

Figure 1. Sample displacement and velocity chart showing segmentation points

The markers used for signal segmentation were the downward peak during the LL opening from the /p/ to the /æ/ in *Patrick*, and the upward peak during the LL closing from the /æ/ to the /p/ in *apples*. These segments were then analyzed for duration and Spatiotemporal Index (STI) for the lower lip (measure of the variability of speech movements over multiple repetitions after time and amplitude normalizing). A sample chart of a low STI is shown in Figure 2, and a sample chart of a high STI is shown in Figure 3. In addition, the gesture for the first syllable of *packed*

(/pækt/) was segmented from the displacement record as shown in the upper chart of Figure 1, and used to make measurements of LL displacement, LL velocity, and UL/LL correlation.

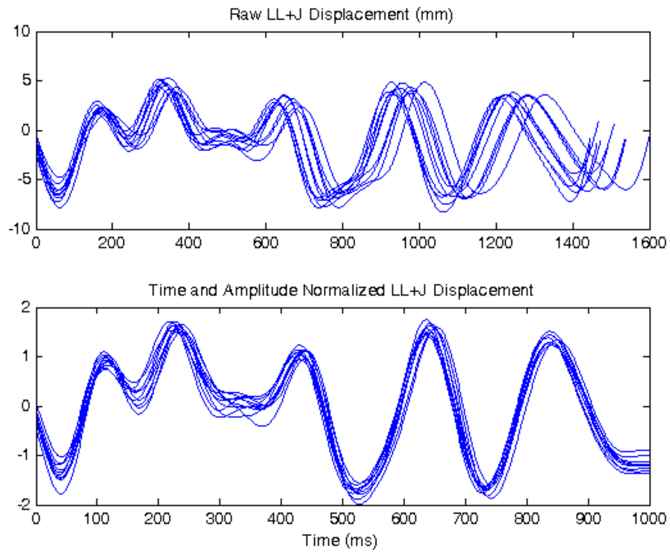

Figure 2. Example of low STI raw and normalized LL displacement charts

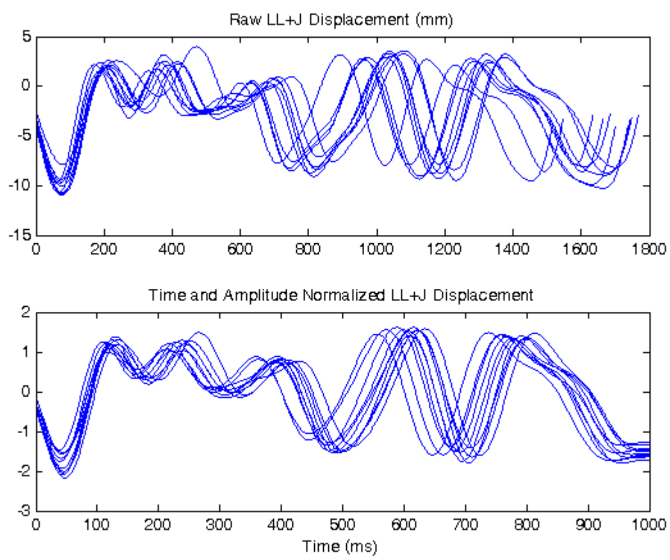

Figure 3. Example of high STI raw and normalized LL displacement charts

Measurements of the non-speech tasks (motor, cognitive, and linguistic) in the isolated condition were taken to compare with the same tasks in the divided attention condition in order to quantify the impact of speaking on these non-speech tasks. The motor task was scored by number of pegs placed in 60 seconds. The cognitive and linguistic tasks were scored by total number of responses and number of correct responses in 60 seconds, as well as accuracy of responses.

Results

Speech dependent measures were based on the average of ten tokens of the target phrase per condition. The utterances were judged as perceptually correct by at least one listener. Tokens judged as correct contained all of the words of the target phrase in the correct sequence, without significant disfluencies. Two participants failed to produce ten correct utterances during the concurrent cognitive task, and measures for those participants in that condition were excluded from analysis. Equipment malfunction prevented the collection of intensity data for one participant across all conditions. In addition, one participant's data for the concurrent manual motor task were not collected due to a procedural error.

The descriptive statistics for each dependent variable were calculated for each of the three age groups and separated within age groups by gender. Descriptive statistics for utterance duration, LL displacement, and velocity are reported in Table 1 and shown graphically in Figure 4. Descriptive statistics for UL/LL correlation, STI LL, and intensity are reported in Table 2 and shown in Figure 5. The descriptive statistics for the linguistic, cognitive, and manual motor non-speech tasks are shown in Tables 3, 4, and 5, respectively.

Repeated Measures ANOVAs

The means of the speech measures for each condition were tested with a repeated measures ANOVA with age group and gender contrasts, followed by post hoc analyses. The same testing was completed for the linguistic, cognitive, and manual motor non-speech tasks, comparing performance between the isolated and concurrent conditions. When Mauchly's test of sphericity was significant, the corrected Huynh-Feldt values were used. Because proportion and correlation coefficient data are typically not normally distributed, they were transformed (arcsine and Fisher z, respectively) prior to analysis. The statistically significant F-ratios and p-values for the speech measures are displayed in Table 6, and for the non-speech concurrent tasks in Table 7. The age effects and age contrasts for the non-speech tasks are shown in Table 8.

Divided Attention Effects on Kinematic Measures and Non-Speech Task Performance

There was a significant main effect of divided attention on all speech variables except LL velocity as shown in Table 6. Duration was significantly longer during the linguistic and cognitive concurrent tasks compared to the speech only condition. Overall LL displacement decreased during the concurrent performance of the manual motor task. Correlation between the UL and LL decreased for the concurrent linguistic and cognitive conditions. The STI of the LL increased during the linguistic and cognitive conditions. Sound pressure level increased only during the manual motor condition.

There was also a significant divided attention main effect on some of the non-speech task measures, as shown by their F-ratios and p-values reported in Table 7. The means and standard deviations of the non-speech task response counts are shown in Figure 6. The linguistic and cognitive task accuracy rates and their standard deviations are shown in Figure 7. Linguistic task measures that significantly differed during divided attention included the number of correct responses and the number of total responses, with both decreasing compared to the single task condition. One cognitive task measure also decreased significantly during divided attention: the number of correct responses. The divided attention condition did not significantly affect the number of pegs the participants placed in the board.

Table 1

Descriptive Statistics for Utterance Duration, LL Displacement, and LL Velocity by Age and Gender for the Speech Only Condition and Three Concurrent Conditions

		Utterance Duration (ms)							
		Speech Only		Language		Cognitive		Manual Motor	
Age	Gender	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
20s	Female	1572.1	142.2	1634.2	167.1	1630.3	162.0	1605.7	216.0
	Male	1634.2	115.6	1706.9	225.1	1665.7	200.2	1616.4	170.4
40s	Female	1625.1	165.8	1735.3	283.4	1767.9	234.4	1620.1	152.9
	Male	1559.5	121.2	1603.6	141.7	1624.8	151.7	1572.1	83.9
60s	Female	1743.6	208.2	1752.5	243.8	1760.3	293.8	1740.7	264.3
	Male	1738.1	215.5	1856.2	202.6	1809.7	189.6	1742.0	153.6

		LL Displacement (mm)							
		Speech Only		Language		Cognitive		Manual Motor	
Age	Gender	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
20s	Female	9.92	2.22	9.22	2.87	9.08	2.56	9.41	2.88
	Male	9.25	2.09	9.03	1.86	9.08	1.90	8.96	2.04
40s	Female	9.97	2.57	10.03	2.92	9.56	2.85	9.26	2.65
	Male	8.96	2.81	9.16	2.82	9.20	3.08	8.74	3.20
60s	Female	9.84	3.58	9.11	2.58	8.89	3.34	8.97	2.75
	Male	10.55	2.80	11.63	2.95	11.27	2.79	10.64	2.47

		LL Velocity (mm/s)							
		Speech Only		Language		Cognitive		Manual Motor	
Age	Gender	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
20s	Female	105.11	27.61	94.51	24.09	95.12	22.14	96.93	30.75
	Male	105.78	23.86	107.76	27.02	105.86	28.85	104.68	27.14
40s	Female	101.04	30.22	108.24	28.94	96.54	29.80	95.08	23.71
	Male	101.35	33.77	100.72	33.25	97.44	38.34	96.19	37.47
60s	Female	91.01	31.76	89.86	32.61	83.69	35.40	86.91	29.74
	Male	109.70	28.49	119.55	26.40	119.15	25.71	120.16	24.30

Table 2

Descriptive Statistics for UL/LL Correlation, LL STI, and Intensity by Age and Gender for the Speech Only Condition and Three Concurrent Conditions

		UL/LL Correlation							
		Speech Only		Language		Cognitive		Manual Motor	
Age	Gender	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
20s	Female	-0.584	0.200	-0.578	0.222	-0.593	0.218	-0.579	0.211
	Male	-0.569	0.162	-0.648	0.177	-0.599	0.207	-0.590	0.212
40s	Female	-0.342	0.348	-0.367	0.382	-0.378	0.352	-0.331	0.460
	Male	-0.377	0.356	-0.461	0.254	-0.402	0.399	-0.369	0.288
60s	Female	-0.321	0.288	-0.388	0.318	-0.407	0.295	-0.343	0.381
	Male	-0.368	0.437	-0.443	0.340	-0.419	0.408	-0.472	0.374

		STI LL							
		Speech Only		Language		Cognitive		Manual Motor	
Age	Gender	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
20s	Female	12.02	2.41	15.77	4.38	15.46	5.12	13.17	4.21
	Male	12.40	2.48	18.03	5.21	14.41	4.34	13.66	3.64
40s	Female	12.26	2.02	23.27	6.73	20.54	7.36	14.24	7.18
	Male	11.69	2.82	16.69	4.93	14.60	4.65	12.29	6.71
60s	Female	12.94	4.22	21.66	7.71	16.92	6.65	15.47	6.76
	Male	13.28	4.96	20.11	6.80	16.90	4.02	13.11	3.88

		Intensity (dB SPL at 100 cm)							
		Speech Only		Language		Cognitive		Manual Motor	
Age	Gender	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
20s	Female	57.98	3.15	58.58	3.06	58.33	2.50	60.06	2.23
	Male	59.36	4.15	59.40	4.68	59.40	4.36	60.83	4.24
40s	Female	54.97	2.10	55.55	2.54	55.13	2.55	57.54	1.73
	Male	55.89	4.67	57.26	5.22	57.15	5.13	59.01	4.75
60s	Female	56.34	5.77	56.20	5.86	55.42	5.96	58.44	6.63
	Male	55.80	5.54	55.73	6.79	56.25	6.66	57.51	6.70

Table 3

Descriptive Statistics for the Linguistic Task in the Isolated and Concurrent Conditions

		Total Responses				Number of Correct Responses				Task Accuracy			
		Isolated		Concurrent		Isolated		Concurrent		Isolated		Concurrent	
Age	Gender	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
20s	Female	41.6	7.1	31.7	8.3	41.1	7.3	30.6	8.2	98.7%	1.4%	96.4%	3.3%
	Male	42.2	4.6	35.8	3.4	41.0	4.8	35.2	2.9	97.1%	3.1%	98.4%	1.8%
40s	Female	38.7	4.3	29.0	7.8	38.1	4.9	28.4	7.9	98.3%	2.4%	97.6%	2.9%
	Male	38.2	5.0	25.8	6.9	37.8	5.0	25.0	6.8	98.9%	1.4%	97.0%	4.6%
60s	Female	32.7	4.9	24.2	7.4	31.3	4.8	22.7	6.7	95.8%	4.3%	94.2%	6.0%
	Male	33.1	3.9	23.9	4.8	31.5	4.1	22.6	4.9	95.1%	3.1%	94.5%	5.1%

Table 4

Descriptive Statistics for the Cognitive Task in the Isolated and Concurrent Conditions

		Total Responses				Number of Correct Responses				Task Accuracy			
		Isolated		Concurrent		Isolated		Concurrent		Isolated		Concurrent	
Age	Gender	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
20s	Female	25.1	7.4	24.9	6.2	23.6	6.9	23.4	5.5	94.0%	2.0%	94.3%	2.8%
	Male	27.6	4.1	28.8	2.8	26.1	3.9	27.8	3.3	94.6%	3.9%	96.4%	4.6%
40s	Female	21.4	2.7	20.3	3.6	20.4	3.1	18.1	4.8	95.2%	4.8%	88.1%	9.3%
	Male	22.8	6.0	21.0	2.7	21.8	6.1	18.7	4.3	95.0%	5.5%	87.9%	13.3%
60s	Female	18.7	4.5	17.8	4.7	16.3	4.8	14.9	4.8	86.9%	12.6%	83.1%	12.5%
	Male	20.8	4.9	19.7	4.3	19.2	5.0	17.0	5.1	91.8%	5.5%	85.5%	12.4%

Table 5

Descriptive Statistics for the Manual Motor Task in the Isolated and Concurrent Conditions

		Number of Pegs Placed			
		Isolated		Concurrent	
Age	Gender	*M*	*SD*	*M*	*SD*
20s	Female	50.0	3.1	48.3	6.0
	Male	43.1	4.8	44.7	4.9
40s	Female	46.0	7.1	46.4	6.7
	Male	38.3	6.3	38.4	10.2
60s	Female	39.1	4.8	35.7	6.6
	Male	35.8	5.5	37.2	6.6

The divided attention effect interacted significantly with gender for two speech variables, LL displacement, $F(2.592,139.992) = 4.344$, $p = .008$, and LL velocity, $F(3,162) = 2.868$, $p = .038$. Although there was no main effect of gender on any of the speech dependent measures, overall LL displacement differed by gender during the linguistic and cognitive conditions in contrast with the isolated speech condition, with $F(1,54) = 5.723$, $p = .02$, and $F(1,54) = 8.786$, $p = .005$, respectively. Displacement increased for males and decreased for females in the linguistic and cognitive conditions compared to the speech only condition. LL velocity differed by gender during the cognitive and manual motor conditions, with $F(1,54) = 6.269$, $p = .015$, and $F(1,54) = 4.213$, $p = .045$, respectively. Velocity decreased for the females and increased for the males during the cognitive and manual motor conditions compared to the speech only condition.

There were no significant interactions of divided attention with age for any of the speech measures. The divided attention condition did interact with age, however, on two measures of the cognitive task: number of correct responses, and accuracy, with $F(2,56) = 4.017$, $p = .023$, and $F(2,56) = 4.145$, $p = .021$, respectively. Both number of correct responses and accuracy decreased to a greater degree as participant age increased. There were no significant interactions of divided attention with gender for any of the non-speech task measures.

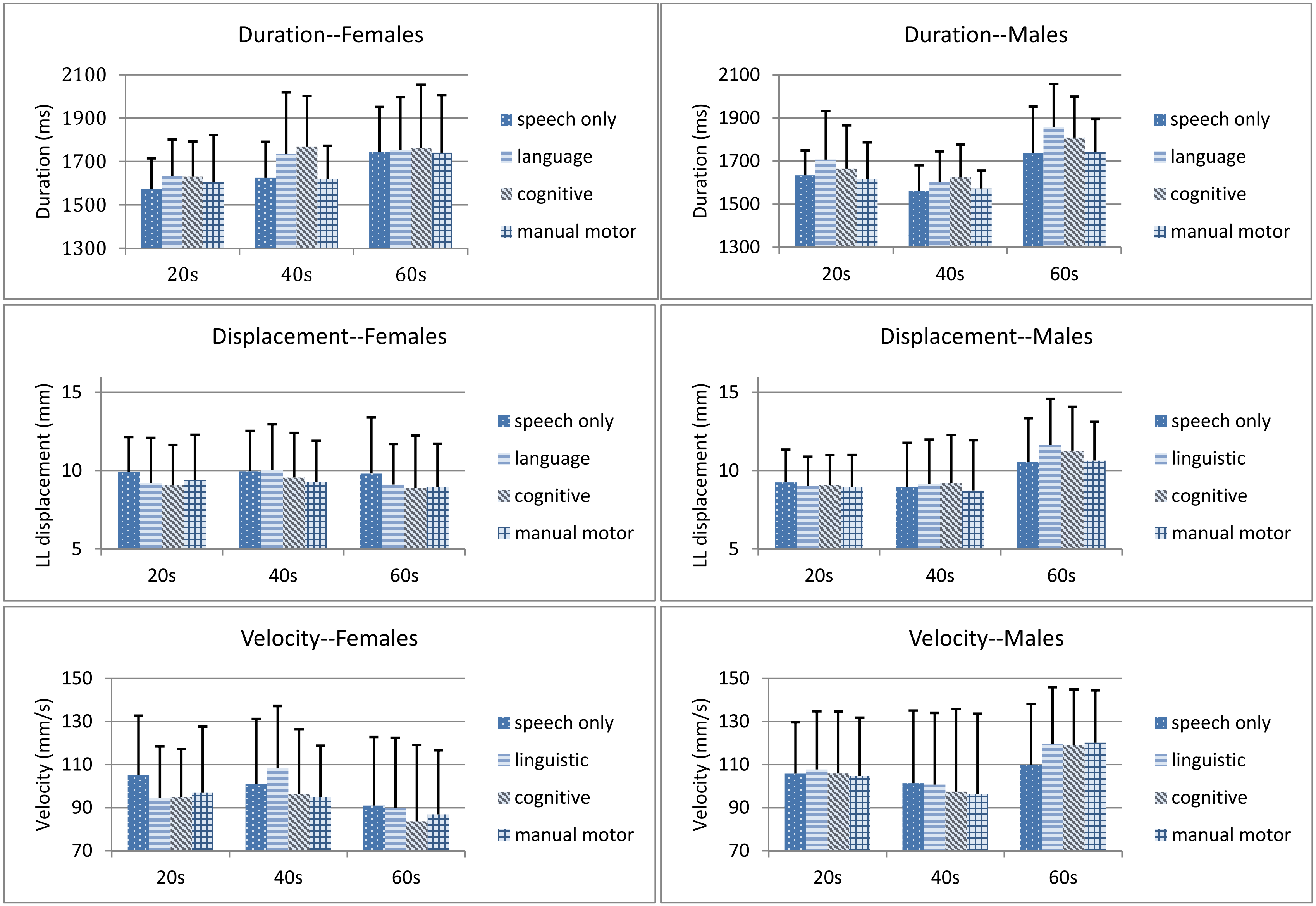

Figure 4. Utterance duration and LL displacement and velocity by gender, grouped according to age

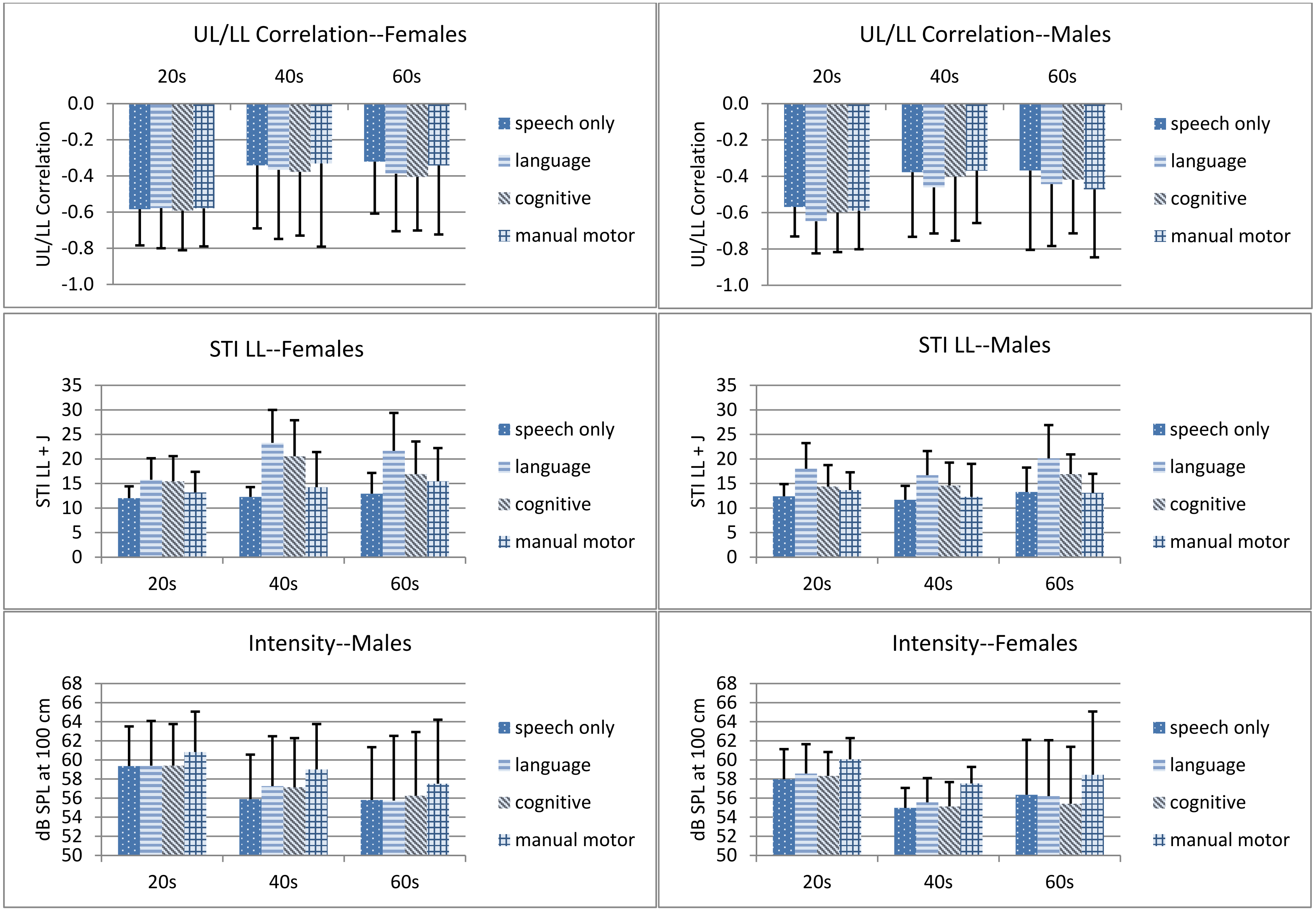

Figure 5. UL/LL correlation, STI LL, and intensity by gender and condition, clustered by age group

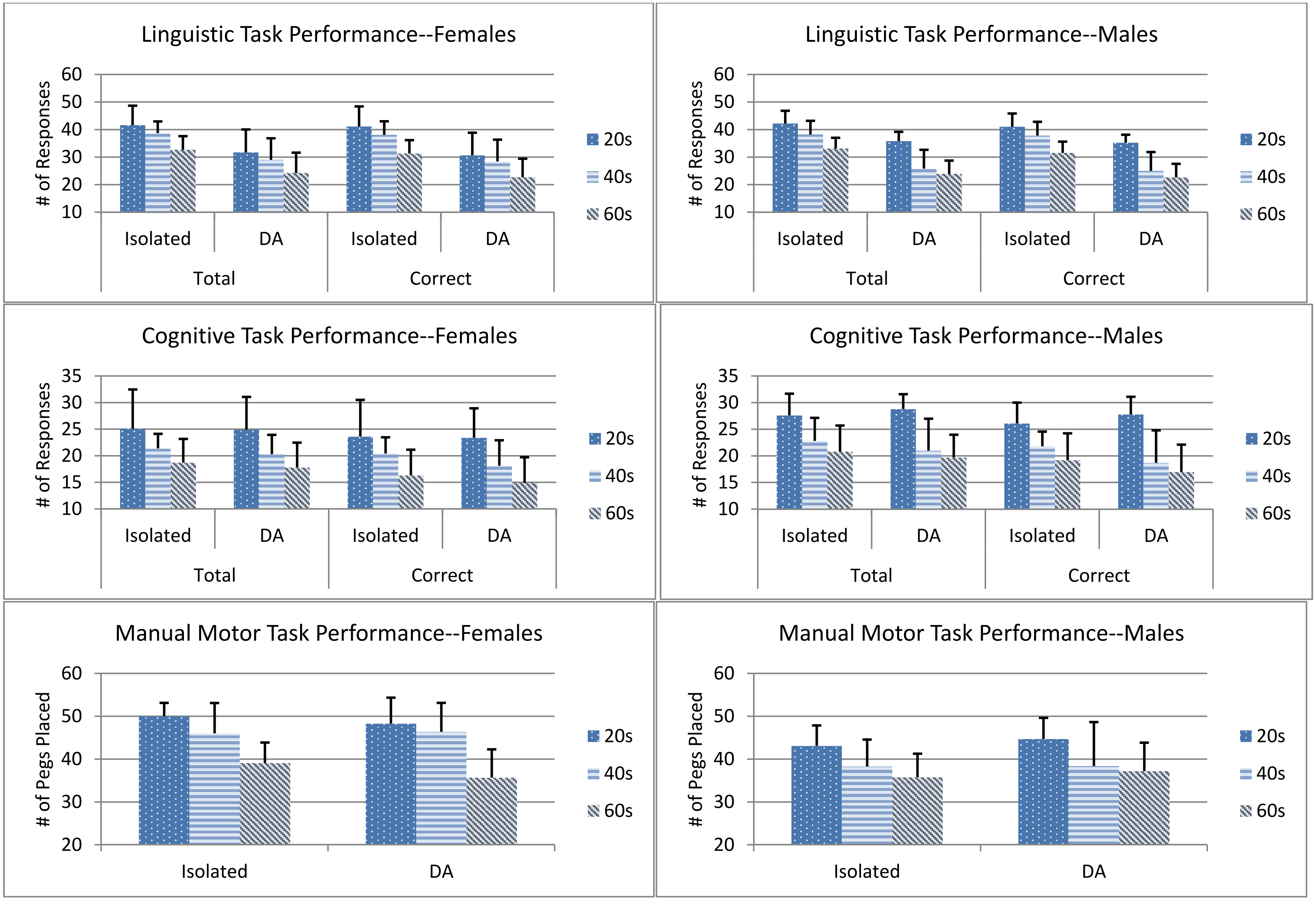

Figure 6. Age group response counts for distractor tasks by gender, grouped by condition

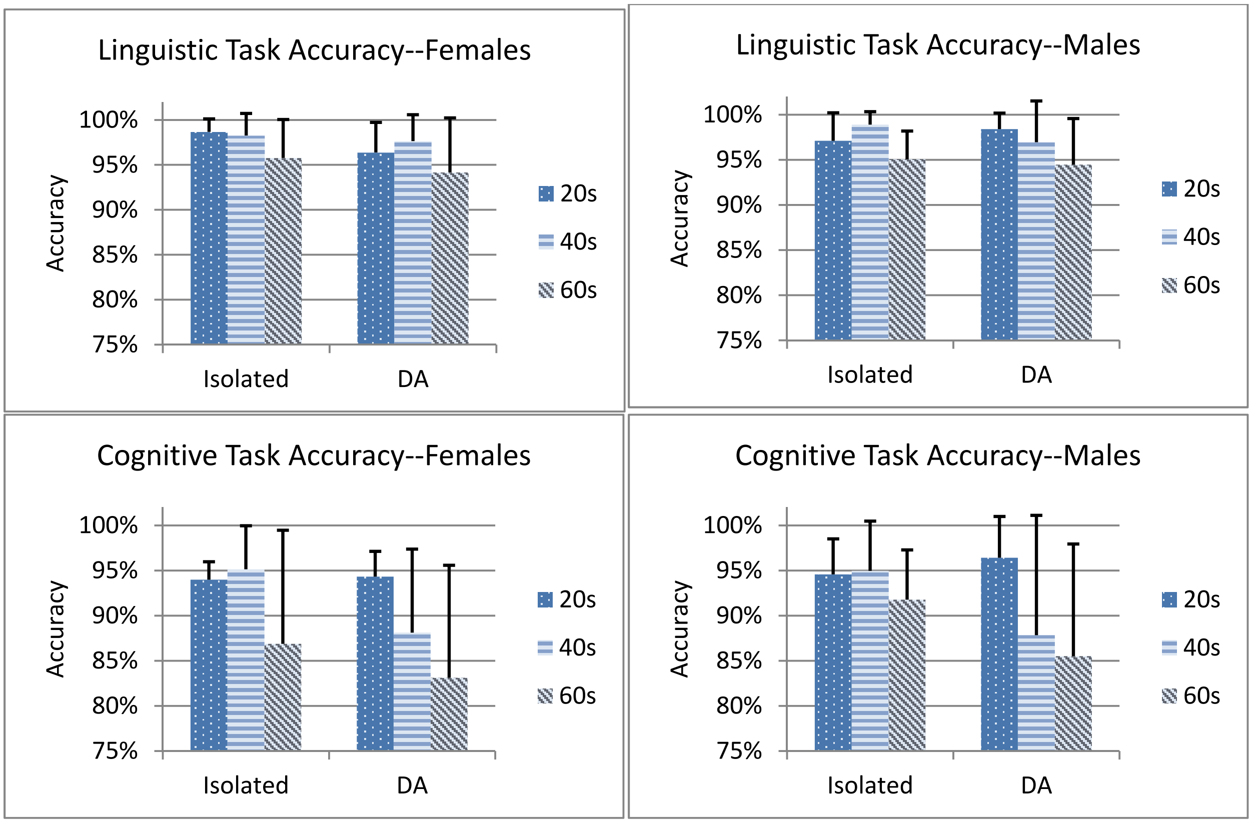

Figure 7. Age group linguistic and cognitive task accuracy by gender, grouped by condition

Age Effects on Kinematic Measures and Non-Speech Task Performance

There was a significant main effect of age on one of the speech variables, segment duration. Duration increased as participant age increased, $F(2,54) = 3.457$, $p = .039$. There were age effects for all variables of the non-speech tasks, and these effects involved many significant contrasts between the age groups, as shown in Table 8. Increases in participant age were associated with decreases in performance for each of the non-speech task variables.

Gender Effects on Kinematic Measures and Non-Speech Task Performance

Gender was not found to have a significant effect on any of the speech measures. It did, however, have a significant effect on manual motor task performance, $F(1,56) = 9.907$, $p = .003$. Females had higher manual motor performance than males.

Table 6

RM ANOVA of Condition Effect on Speech Measures, With Concurrent Task Contrasts Against the Isolated Speech Condition

	Condition Main Effect			Language Contrast			Cognitive Contrast			Manual Motor Contrast		
	F	*p*	*df*	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*	*df*
Duration (ms)	11.999	<.001	2.558, 138.109	12.105	0.001	1,54	18.186	<.001	1,54			
Displacement (mm)	3.252	0.03	2.592, 139.992							5.732	0.02	1,54
LL Velocity (mm/s)												
UL/LL Correlation	3.381	0.023	2.781, 150.165	9.329	0.003	1,54	5.899	0.019	1,54			
STI LL	29.399	<.001	3, 162	68.838	<.001	1,54	29.538	<.001	1,54			
dB SPL at 100 cm	32.998	<.001	2.759, 146.201							65.017	<.001	1,53

Table 7

RM ANOVA of Divided Attention Effect on Non-Speech Task Performance

		Divided Attention Effect	
Distractor Task		*F*(1,56)	*p*
Linguistic	Number of Correct Responses	210.826	<.001
	Total Number of Responses	211.928	<.001
	Accuracy		
Cognitive	Number of Correct Responses	5.879	0.019
	Total Number of Responses		
	Accuracy		
Manual Motor	Number of Pegs Placed		

Table 8

Age Effect and Contrasts for Non-Speech Task Performance Measures

Distractor Task		$F(2,56)$	p	20 vs 40 p	20 vs 60 p	40 vs 60 p
Linguistic	Correct Responses	17.054	<.001	0.023	<.001	0.008
	Total Responses	15.178	<.001	0.015	<.001	0.03
	Accuracy	6.194	0.004		0.032	0.004
Cognitive	Correct Responses	18.308	<.001	0.001	<.001	
	Total Responses	15.642	<.001	0.001	<.001	
	Accuracy	5.790	0.005		0.004	
Manual Motor	Pegs Placed	13.718	<.001		<.001	0.016

Discussion

This study was designed to investigate the effects of three concurrent tasks on speech motor performance, as well as the influence of speech on those tasks. It was also designed to examine the effects of age on divided attention performance, with the hypothesis that older adults would experience more dual task interference than younger adults. The results of the present study are consistent with the previous findings of Dromey and Benson (2003) and Dromey and Bates (2005) and expand on them, providing a clearer picture of the bidirectional interference between speech and non-speech tasks, and also how age affects speech motor performance. In addition, the results provide evidence that divided attention affects cognitive task performance more in older adults than it does in younger adults.

Impact of Independent Variables

Concurrent Task Effects on Speech. Although the effects of concurrent task type on speech motor performance were already investigated by Dromey and Benson (2003), the present study likely involved a more comprehensive division of attention. The designs of Dromey and Bates (2005) and Dromey and Benson (2003) may have allowed participants to switch between the speech task and the non-speech tasks in the divided attention condition. In the linguistic distractor condition of Dromey and Benson, participants generated a verb from a noun and spoke it at the end of the sentence, *Mr. Piper and Bobby would probably pick….* In their cognitive task, participants counted backwards from 100 by sevens, providing one answer after each repetition of the carrier phrase for the speech task. The cognitive task of Dromey and Bates involved a two-digit subtraction problem, which was also spoken at the end of the target sentence in the dual task condition. Dromey and Bates noted that pauses in responses for the cognitive task and anecdotal evidence from participants suggest that participants may have finished part of the speech task before completing the cognitive task. Thus this sequential arrangement of task responses may not have represented the intended divided attention condition. In contrast, the non-speech tasks in the present study did not require verbal responses, allowing participants to select answers while they spoke. This arrangement allowed for truly concurrent task performance, and thus a clearer understanding of bidirectional interference.

The nature of the task being performed concurrently with speech led to different effects on all of the speech measures except velocity. Each task, linguistic, cognitive, and manual motor, affected these measures differently, which gives insight into the level of attention each may require. Concurrent performance of the linguistic task significantly increased utterance duration, increased negative UL/LL correlation, and dramatically increased STI of the LL. Concurrent performance of the cognitive task affected speech performance in a very similar manner to the linguistic task, also increasing utterance duration, increasing negative UL/LL correlation, and increasing STI of the LL. The linguistic task was associated with a greater increase in LL STI than the cognitive task. It could be inferred that the linguistic task interfered more than the cognitive task with speech. This is directly in line with what the functional distance hypothesis of Kinsbourne and Hicks (1978) predicts, as the neural centers for language formation are closer to speech motor control centers than are the centers responsible for quantitative reasoning.

Concurrent performance of the manual motor task had a much different impact than the linguistic and cognitive tasks on speech motor performance. Instead of increasing duration, correlation, and STI, concurrent manual motor performance led to an overall decrease in LL displacement and an increase in intensity level. This is similar to what was found by Dromey and Shim (2008), except that they also found a statistically significant reduction in velocity, which the present study did not find, although there was a trend in that direction. One possible reason for this increase in vocal intensity was the ease with which participants could keep track of their performance on the pegboard, which may have led them to try to improve their performance from the practice trial. Participants may have become more involved with their participation, leading to greater intensity.

The differential effects of the task type could be explained by the multiple capacities model proposed by Navon and Gopher (1979). Their model predicted that similar tasks would interfere more than dissimilar tasks, with similar tasks drawing on the same pool of attentional resources and dissimilar tasks drawing on different pools. In the present study, the linguistic task interfered the most with speech motor control and was a more similar task than the cognitive or manual motor task. The cognitive task in turn interfered more than the manual motor activity, and could also be considered a more similar task.

An alternative model, the functional distance hypothesis of Kinsbourne and Hicks (1978), could also explain the present results. This hypothesis predicts that two tasks will interfere more when the brain regions controlling them are closer together anatomically. In the present study the semantic reasoning task interfered most with speech stability, followed by the closely-related quantitative reasoning task, in turn followed by the manual motor task. The data suggest that cortical centers responsible for speech motor control are more susceptible to the attentional demands of concurrent linguistic activity than to concurrent cognitive or manual motor activity, but also more susceptible to the demands of concurrent cognitive activity than manual motor activity. The non-speech task scores in the isolated condition suggest that the cognitive task may have been harder, with participants overall responding fewer times. However, the linguistic task affected their speech motor performance more, which suggests that concurrent task difficulty was not the issue, even though task difficulty has been cited as a factor in divided attention performance (McDowd & Craik, 1988). Rather, the fact that the linguistic task affected speech more, even though it could be considered an easier task than the cognitive, is evidence in support of the functional distance hypothesis.

Influence of Speech on Concurrent Non-Speech Tasks. The non-speech tasks were measured on their own as well as concurrently with speech in order to examine the effect that speech had on them. The data show that concurrent speech was associated with decreases in linguistic and cognitive task performance. These results provide strong evidence of the influence of speech on non-speech tasks, supporting findings by Dromey and Bates (2005), who found that concurrent speech was associated with a decrease in ability to sequence words into a sentence. However, concurrent speech was not associated with significant changes in manual motor performance. Other studies have found that measures of gross motor performance can be affected by concurrent speech. Dromey et al. (2010) and Holmes, Jenkins, Johnson, Adams, and Spaulding (2010) found that concurrent speech was associated with declines in several measures of postural stability in healthy and neurologic participants. One possible reason that the present data did not reflect a decrease in manual performance is that there may be differences in the susceptibility to divided attention of manual motor versus postural stability. Another possible reason is that the manual motor task in this study may not have sufficiently challenged participants' manual motor control.

Age Effects On Performance in Both Isolated and Divided Attention Conditions. Age was associated with a difference in one of the speech measures, utterance duration, which increased overall with age. This finding suggests that age is accompanied by a general slowing of speech movements. The lack of an increase in STI suggests that the slowing may be a strategy to maintain stable motor control. The slowing could explain the finding of Ballard, Robin, Woodworth and Zimba (2001) that older adults had greater difficulty controlling the lower lip, jaw, and fundamental frequency in response to visual feedback. Although their study purposefully excluded overt linguistic impacts in order to measure non-speech articulator movement, the general age-related slowing of articulator control they found could also be present in articulator control during the repetition of a real sentence, as in the present study.

There were age-related differences for all seven of the non-speech task measures. Older adults responded fewer times during the linguistic and cognitive tasks, were less accurate on both tasks, and placed fewer pegs, regardless of condition. The pegboard findings reflect the manual motor trends reported in the Purdue Pegboard normative data (1948) and by Talland (1962), which show that older adults exhibit reduced manual motor performance compared to younger adults. The other findings show that the linguistic and cognitive tasks were simply harder in general for older adults. The age contrasts may give insight into when these changes occur. The 20s significantly differed from the 40s on the total number and number of correct responses for both the cognitive and linguistic tasks. However, the 20s were not significantly different from the 40s on the accuracy measures for both tasks, indicating that the age effect on task accuracy occurred gradually between the 20s and the 60s. The 40s versus 60s age contrast for linguistic task accuracy indicated that accuracy declined within that timespan. Similarly, the age effect on manual motor performance seems to occur between the 40s and 60s, suggesting that linguistic accuracy and manual motor task performance may change between the 40s and 60s, while cognitive task accuracy changes more gradually between the 20s and 60s.

Divided attention interacted with age on measures of the cognitive task only. The decrease in the number of correct responses and the accuracy rate during divided attention was greater for older adults than younger. In other words, the already lower accuracy rate of the older adults decreased even more while speaking than it did for the younger adults. Dromey et al. (2010) found that heel height in a rise-to-toes postural stability task was affected by a speech task more in older adults, both healthy and with neuropathology, than it was in the younger adult control group. Chen et al. (1996) found that older adults had greater difficulty than younger adults dividing their attention between an obstacle avoidance task and a selective attention task requiring a verbal response to visual stimuli. The present study provides some limited confirmation that the effects of divided attention increase with age.

Gender Differences. Gender did not have an impact on any of the speech dependent measures, in contrast with the findings of Dromey and Benson (2003). They found a significant divided attention and gender interaction, with males having a higher LL STI than females when performing a linguistic or cognitive dual task while speaking. This difference in findings could be due to differences in the task (backwards counting by sevens versus quantity comparisons) or differences in the sample size (20 participants versus 60).

Gender did have a significant effect on one of the non-speech tasks, manual motor performance task, with females placing more pegs than males. The normative data for the

Purdue Pegboard Test indicate that females generally place more pegs than males. Although our methodology did not follow the exact protocol for administering the Purdue Pegboard Test, the data from our study reflect the same gender trend.

Limitations and Directions for Future Study

Some of the limitations of this study related to the tasks used and the conditions required for calculating STI. The tasks were chosen as representative of complex behaviors and were selected in part to limit data collection time to a reasonable level. Further studies could explore whether other linguistic demands, such as those required for morphological or phonological tasks, might have an effect similar to the semantic decision task. Further studies could also explore other cognitive tasks, since quantitative reasoning is only one aspect of cognition. Due to the equipment required for the kinematic measures, participant gross motor movement was significantly restricted; however, with advanced, wireless equipment, more complex motor movements could be used as tasks concurrent with speech.

Another limitation was the unnatural nature of the speaking task. Calculating the STI for a condition requires ten tokens of the same utterance, but repeating an utterance ten times in a row lacks ecological validity, because such speech behaviors are not part of daily life. Future studies ideally could examine how kinematic measures of generative speech may differ from those of repetitive speech in divided attention conditions. A potential design that could achieve this would elicit the target response without directly requesting its repetition. One way this could be done would be to administer a large set of questions, at least ten eliciting the target response for STI analysis. This could increase the ecological validity of the experiment and better represent functional speech.

Finally, the present study examined healthy adults in three age groups. Further studies could increase understanding of speech and divided attention by examining other speakers, such as pediatric or disordered populations.

Conclusion

This study, with its substantial sample size, confirms the findings of several previous divided attention studies. The data reveal aspects of speech motor performance across fifty years of the adult lifespan. They also provide a clearer picture of the effect that task type has on speech motor performance during dual task situations, lending at least some support to the functional distance hypothesis of divided attention. Further, the present results give insight into the effect of speech on the concurrent performance of various non-speech tasks. Future research could examine divided attention under conditions that allow greater ecological validity and address a broader array of non-speech tasks.

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Appendix A

Annotated Bibliography

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Objective: The purpose of this study was to provide normative data across the lifespan for non-speech visuomotor control of the lower lip, jaw, and larynx. *Method*: 87 participants (52 females and 35 males) ages 8:2 to 84:3 were seated in front of a screen with a visually presented target. The target moved either unpredictably, or at one of three stable frequencies. The participants were fitted with a strain gauge cantilever system that was attached to the lower lip and to the jaw to measure their movements. A microphone measured fundamental frequency as an acoustic measure of laryngeal movement. The signals were transduced and represented as a dot on the screen along with the visual target. The participants were instructed to track their signal to follow the target signal during each experimental trial. The cross correlation, gain ratio, phase shift, and average difference between the target and tracking signals for the experimental trials were examined. *Results*: Correlation between the visual target and the 50th percentile curve of the tracker signal in each condition revealed age range trends: correlation began low at 8 years of age, was fairly level from 15 to 20 years of age, and began to decrease again at 40-45 years of age. Participants between 17 and 45 years of age also had the lowest target-tracker amplitude difference. *Conclusion*: Accuracy of amplitude matching for each of the three articulators studied increased during development and began to decrease with aging in middle adulthood. Age influenced within-person temporal variability but not within-person amplitude variability. *Relevance to the current work*: Aging is shown to be a significant factor in articulator movement performance in visuomotor tasks. Age is a logical variable to examine in the present articulator movement study.

Brooks, L. R. (1968). Spatial and verbal components of the acts of recall. *Canadian Journal of Psychology/Revue canadienne de psychologie, 22*(5), 349-368. doi:10.1037/h0082775

Objective: This series of dual-task experiments addressed the relationship between the type of tasks performed (verbal versus visual) and the resulting level of interference. *Method*: Seven distinct experiments were performed. All participants were undergraduate university students. In each experiment, the participants were asked to perform various verbal and visual tasks in a dual-task format. In some trials, both tasks were more verbal in nature; in other trials, both tasks were visual; in still other trials, one task was verbal and the other was visual. In experiment one, an example of a verbal task was listening to a sentence and completing a secondary task of labeling each word as a noun or non-noun. This labeling could be done in a verbal manner by saying “yes” or “no” or some other set of words; it could also be done in a visual manner by pointing to a “Y” or an “N” on a piece of paper. The visual task involved looking at a complicated block design and performing a secondary task of labeling each corner of the design as being on the top, bottom, or somewhere in between. This labeling could also be done in a verbal or visual manner. *Results*: Participants were slower in completing the set of experimental trials when the task and the method of labeling, or the secondary task, were both of the same basic modality (i.e., both visual or both verbal). Conversely, participants were faster at completing the experimental trials when the two tasks differed (i.e., when performing verbal-visual pairs of tasks). *Conclusion*: Task type is a very important factor affecting the amount of interference in dual-task paradigms. *Relevance to the current work*: This finding, the effect of task on interference in divided attention conditions, led to significant developments in divided attention theory.

Camicioli, R., Howieson, D., Lehman, S., & Kaye, J. (1997). Talking while walking: The effect of a dual task in aging and Alzheimer's disease. *Neurology, 48*(4), 955-958.
Objective: The study was performed to evaluate the effect of distraction on gait in older adults with and without Alzheimer's disease. *Method*: Three groups of participants were evaluated in the study: a Young Old (yOld) group (*M* = 72 years), an Old Old (oOld) group (*M* = 86 years), and an Alzheimer's disease (AD) group (*M* = 74 years). The yOld and oOld groups were evaluated with a series of physiological, cognitive, and emotional examinations, as well as an MRI of their brains, to determine they were in good overall health, with exceptions for osteoarthritis and hypothyroidism. The AD group consisted of participants diagnosed with probable Alzheimer's disease without parkinsonism. All participants performed a walking task and a verbal fluency task; each task was performed once separately, and the tasks were also performed concurrently in a dual-task format. The verbal fluency baseline consisted of listing as many animal names as possible in 60 s. The baseline walking task consisted of walking down a 15 foot hallway, turning around, and walking back. The dual-task consisted of performing the walking task while reciting as many male names as possible. The dual-task was then repeated, only with female names being recited. Measures that were taken included length of time taken to finish walking and number of steps taken. *Results*: All groups were slower and took more steps while performing the combined tasks. The AD group was slowed significantly more by the verbal fluency task than the yOld and oOld groups. The yOld and oOld groups did not significantly differ from each other. *Conclusion*: Alzheimer's disease affects gait during divided attention more than age alone does. *Relevance to the current work*: The study shows that divided attention affects gait, even in healthy individuals.

Camicioli, R., Oken, B. S., Sexton, G., Kaye, J. A., & Nutt, J. G. (1998). Verbal fluency task affects gait in Parkinson's disease with motor freezing. *Journal of Geriatric Psychiatry and Neurology, 11*(4), 181-185.
Objective: The study evaluated the effect of a verbal fluency task on gait in individuals with and without Parkinson disease. Individuals with Parkinson's included those with and without freezing, a symptom involving difficulty initiating and maintaining gait. *Method*: The study involved 38 participants, divided into three groups: the Parkinson's disease non-freezing group (PD-NF; n = 9, *M* = 72.0 years), the Parkinson's disease freezing group (PD-F; n = 10, *M* = 67.3 years), and the healthy control group (n = 19, *M* = 71.7 years). PD-F participants with mild dementia were excluded from the study. Two experiments were performed which were identical except for a medication variable: in Experiment 1, all participants performed the trials when they felt their medications were working effectively; in Experiment 2, the PD-F group was tested after being off their medications for ten to twelve hours, and then again 90 min after taking their medications. The participants were asked to perform a baseline walking task, then the same task again while concurrently listing as many male names as they could. The researchers measured the time and number of steps taken to complete the walking task in both the single and dual-task conditions. *Results*: All participants increased in time and number of steps when performing the walking and verbal fluency tasks together. Experiment 1 found that the PD-F group changed

more from their baseline on both measures than the other two groups. The PD-NF group took more steps, but was not slower, than the control group. Experiment 2 found that antiparkinsonian medications reduced the frequency of freezing while walking and concurrently performing the verbal fluency task. *Conclusion*: Performing a verbal fluency task while walking affects the gait of individuals with and without Parkinson's disease. This effect is greater in those with Parkinson's disease than healthy controls. Individuals with Parkinson's disease who experience freezing in their gait are more susceptible to gait changes while speaking than those who do not experience gait freezing. Antiparkinsonian medication causes performance of PD patients with freezing to resemble performance of PD patients without freezing, although it does not remove the effect of the disease. *Relevance to the current work*: The study shows that talking while walking affects gait, even in healthy individuals.

Chen, H.-C., Schultz, A., Ashton-Miller, J., Giordani, B., Alexander, N., & Guire, K. (1996). Stepping over obstacles: Dividing attention impairs performance of old more than young adults. *The Journals of Gerontology, 51A*(3), M116-M122.

Objective: The study was designed to compare the relative divided attention performance of young and older adults in a gross motor obstacle avoidance task and visual response task. The goal was to find whether or not older adults have poorer obstacle avoidance ability when their attention is divided, which could be a factor in falls. *Method*: Thirty-two participants participated in the study, including eight males and eight females in both age groups. The average age for the young adult group was 23.9 years, and for the older adult group was 72.1 years. After screening participants for any impairment that might affect their gross motor ability or vision, the researchers attached safety harnesses to the participants to prevent falls during experimental trials. For the obstacle avoidance task, the participants were asked to walk along an 8 m walkway that detected the placement of their feet and estimated their walking speed. A computer predicted the placement of the next footfall and a projector placed a narrow band of light at that position on the walkway. The participants were asked to avoid stepping on this lighted obstacle. For the visual response task, a collection of LEDs was turned on, and the participants were instructed to say "ah" as soon as they could after seeing LEDs that were red. A microphone captured this vocal response and the time delay between the presentation of the light and the vocal response was recorded. The researchers included two types of this visual response task: the first was a synchronized condition, in which only red diodes were lit, and the timing of the presentation of the diodes was coordinated with the light obstacle; the second was an unsynchronized condition, in which red diodes alternated in presentation along with yellow and green diodes, and their presentation was not synchronized with the lighted obstacle. After various practice and baseline trials of performing the tasks in isolation, the participants completed a total of 81 trials of the obstacle avoidance task performed simultaneously with either of the two forms of the visual response task. The participants were not instructed as to priorities unless they asked, in which case they were told to do their best at both tasks. *Results*: It was found that for all test conditions, young adults performed better on the obstacle avoidance task than older adults. Divided attention significantly decreased obstacle avoidance performance in both groups, although to a greater degree for the older group. There was no significant difference in obstacle avoidance performance between the two different visual response tasks, although both age groups had significantly more errors in the visual response task in the unsynchronized condition compared to the synchronized condition. *Conclusion*: Older adults have greater difficulty than younger adults avoiding obstacles when their attention is divided. The researchers postulate that this difference may be related to the increased difficulty of performing two tasks simultaneously, rather than a specific decline in divided attention performance. *Relevance to the current work*: This study provides further evidence that older adults have greater difficulty dividing attention than younger adults.

Craik, F. (1977). Similarities between the effects of aging and alcoholic intoxication on memory performance, construed within a 'Levels of Processing' framework. In B. I. M. P. E.S. (Ed.), *Alcohol and Memory* (Vol. 3, pp. 9-21). Hillsdale, NJ: Lawrence Erlbaum Associates.

Objective: This book chapter discusses how the effects of alcohol intoxication on memory encoding resemble the effects of aging. *Content*: Craik discusses a memory-encoding model known as levels of processing. He reviews literature that supports the theory. He then discusses how age affects memory and how these age effects have been shown to resemble alcohol intoxication effects on memory. *Relevance to the current work*: Within his discussion of the similarities between the effects alcohol intoxication and those of aging, Craik suggests that both may be mimicked by divided attention conditions. Although he is referring to memory encoding, other tasks requiring attention may be similarly affected.

Dromey, C., & Bates, E. (2005). Speech interactions with linguistic, cognitive, and visuomotor tasks. *Journal of Speech, Language, and Hearing Research, 48*(2), 295-305. doi:10.1044/1092-4388(2005/020)

Objective: The study examined the bidirectional interference of speech and concurrently performed linguistic, cognitive, and visuomotor tasks. *Method*: Ten females (M = 22.9 years of age) and ten males (M = 24.5 years of age) participated in the study. They were fitted with a strain gauge system, which was attached to both lips and the jaw to gather kinematic data. They were recorded during experimental trials with a microphone, and their vocal intensity was measured with a sound level meter. The participants performed speaking, linguistic, cognitive, and visuomotor tasks, each on their own for baseline performance. Each of the latter three were then performed concurrently with the speech task for the experimental trials. The speech task consisted of repeating the phrase, “Peter Piper would probably pick apples,” or something very similar, fifteen times. The linguistic task consisted of correctly sequencing words of a scrambled sentence visually presented on a computer monitor. The cognitive task consisted of completing two-digit subtraction math problems. The visuomotor task consisted of using a computer mouse to click on a moving target on a monitor as many times as possible. Measures for the speech task included utterance duration, lip displacement from /aɪ/ to /p/ in “Piper”, peak velocity at the second /p/ in “Piper”, correlation between the upper lip and lower lip/jaw displacement, spatiotemporal index (STI) for the lower lip/jaw displacement, and SPL. Measures for the other tasks included latency and accuracy of response for the linguistic and cognitive tasks for the combined condition compared to the isolated condition, and number of clicks in a given time for the visuomotor task. *Results*: Lower lip/jaw displacement decreased in the combined visuomotor task compared to the speech-only task. STI increased in the combined linguistic task compared to the speech-only task. SPL increased in all combined tasks compared to the speech-only condition. Latencies were larger for the combined linguistic task than for the linguistic-only task, while they were unchanged for the combined cognitive and combined visuomotor tasks compared to their isolated counterparts. *Conclusion*: When performing the combined linguistic tasks, participants’ speech was louder and had less consistent labial movements, and their linguistic scores decreased when compared to performance on both tasks individually. As this effect was not seen with the combined cognitive and combined visuomotor tasks, the results support the functional distance hypothesis. However, the apparent lack of interference between speech and concurrently performed cognitive and visuomotor tasks could have been due to lack of difficulty or complete simultaneity of the tasks. *Relevance to the current work*: The study gives quantitative evidence of bidirectional interference between speech and linguistic tasks in divided attention conditions.

Dromey, C., & Benson, A. (2003). Effects of concurrent motor, linguistic, or cognitive tasks on speech motor performance. *Journal of Speech, Language, and Hearing Research, 46*(5), 1234-1246. doi:10.1044/1092-4388(2003/096)

Objective: The study purpose was to objectively measure lip and jaw movements during various types of task in a divided attention paradigm. The tasks were a speech task and a linguistic, cognitive, or simple motor task. *Method*: Ten male and ten female young adults participated in the study. Each was fitted with a strain gauge system attached to both of the lips and the jaw. Their speech was recorded with a microphone. The participants completed a speech only task, a speech and motor dual task, a speech and cognitive dual task, and a speech and linguistic dual task. The motor task required the individual to assemble nuts and bolts. The cognitive task required the individual to perform mental arithmetic by counting backwards by seven from 100. The linguistic task required the individual to generate verbs that would match the nouns that were presented. During each trial of each condition, the participant spoke some version of a phrase that contained several bilabial stops. Measurements included the duration of the utterance, the articulator displacement for a specified bilabial gesture, the peak velocity for that movement, the correlation between upper and lower lip displacement, and the spatiotemporal index (STI - a measure of overall variability across 10 repetitions after amplitude and temporal normalization). *Results*: During the motor dual task, lower lip displacement and velocity decreased, but there was no change in STI. During the linguistic dual task, the STI increased significantly for the lower lip; there was a strong negative correlation between lips; and there was a significant gender interaction effect, with males showing comparatively larger STI increases for the dual task condition. During the cognitive dual task, duration decreased, STI for the lower lip increased, and there was again a strong negative correlation between lips and a significant gender effect, with increasing STI values for the men compared to the women. *Conclusion*: The results support a limited resource model of attention and indicate that concurrent performance of a speech task and another task significantly affects articulator movements in healthy young adults. *Relevance to the current work*: This study indicates that speech movements are significantly affected by other concurrent processes.

Dromey, C., Jarvis, E., Sondrup, S., Nissen, S., Foreman, K. B., & Dibble, L. E. (2010). Bidirectional interference between speech and postural stability in individuals with Parkinson's disease. *International Journal of Speech-language Pathology, 12*(5), 446-454. doi:10.3109/17549507.2010.485649

Objective: This study evaluated the bidirectional interference experienced by participants with Parkinson's disease (PD) in divided attention conditions. *Method*: The study used nine participants with PD, seven age-matched controls, and ten young controls. The average age for the PD group was 68.70 years, 70.50 years for the age-matched controls, and 25.50 years for the young controls. The PD participants were asked to have taken their dopamine medications one to two hours prior to the experimental trials. Participants were fitted with reflective markers on their clothing to enable body movement measurements by a motion analysis camera system. They then were directed to stand on a force plate. Participants were asked to perform a speech task and a postural stability task five times each in a single task condition and five times together in a divided attention condition. The speech task consisted of repeating two sentences that had been prepared by the researchers. These sentences targeted the corner vowels and major diphthongs. The postural stability task directed the participants to move from a typical standing position to standing on their toes, holding that position for 5 s, then lowering back to the typical standing position. Analysis of the speech task consisted of measuring the diphthong duration and the F1 and F2 formant extents and slopes. Analysis of the postural stability task consisted of measuring reaction time, as well as computing the center of mass (COM), or point in the body at which mass is evenly distributed, from the visually recorded information, and computing the center of pressure (COP), which is the average of all the vertical forces on the force plate. *Results*: Between groups, there were no differences for the diphthong /ɔɪ/. The duration of the diphthong /eɪ/ was shorter for the younger group than the older groups, and its F2 extent was smaller for the younger group than for the PD group. Healthy young adults had a larger COM-COP difference and heel height than the older groups. Between the single task and dual task conditions, only the PD group experienced a decrease in F1 extent and slope for /ɔɪ/, and a decrease in F2 extent and slope for /eɪ/. Although reaction time for the postural stability task in the divided attention condition increased for all three groups, the differences were only significant for the young and PD groups. Heel height decreased for both older groups compared to the younger group. Overall, the PD group experienced greater decline in postural stability during divided attention than the other groups. *Conclusion*: Divided attention affects individuals with PD more than neurologically healthy same-aged counterparts. Although the speech measures were only slightly worse for the PD group in the divided attention condition, speech affected their postural stability more than it affected the other groups' stability. Thus concurrent performance of a postural stability task and speech task led to more bidirectional interference for the PD group than for the control groups. *Relevance to the current work*: Although the study was designed to examine individuals with PD, the use of healthy same-age controls and younger controls gives insight into the effect of age on interference in neurologically healthy individuals. The study supports age as a factor in divided attention performance.

Dromey, C., & Shim, E. (2008). The effects of divided attention on speech motor, verbal fluency, and manual task performance. *Journal of Speech, Language, and Hearing Research, 51*(5), 1171-1182. doi:10.1044/1092-4388(2008/06-0221)

Objective: This research project was designed to evaluate the functional distance hypothesis of interference during divided attention tasks. *Method*: Ten females (M = 21.0 years of age) and ten males (M = 22.8 years of age) participated in the study. They were fitted with a strain-gauge system, which was attached to both lips and the jaw to gather kinematic data. Their speech during experimental tasks was recorded with a microphone. All participants included in the study demonstrated strong right-hand dominance, which was based on their mean score of 91.0 out of 100 on the Edinburgh Handedness Inventory. The participants were asked to perform a speech motor task, a verbal fluency task, and a manual motor task, each in isolation. They were also asked to perform the manual motor task concurrently with each of the other two tasks to create a divided attention condition. The speech motor task consisted of repeating the phrase "Peter Piper picked a peck of pickled peppers" a total of fourteen times. The verbal fluency task consisted of listing as many words starting with a given letter as possible in a 60 s period. The manual motor task consisted of performing the Purdue Pegboard Test for 60 s with one hand; the task was then performed a second time with the other hand. Measures for the speech motor tasks included utterance duration, lower lip displacement and velocity of the closure into the second /p/ of "Piper," spatiotemporal index (STI), and sound pressure level (SPL). The measure of verbal fluency was the number of correct responses for the word finding task. The measure for the manual motor task was the number of pegs and washers placed on the board. *Results*: Lower lip displacement and peak velocity decreased significantly and SPL increased significantly during the manual motor task regardless of which hand was being used. The STI increased when participants performed the manual task with their left hand. Scores for the motor task decreased significantly for both hands during the verbal fluency task, but not the speech motor task. *Conclusion*: As expected, divided attention conditions led to a decrease in speech motor performance when compared to the control condition. The increase in STI during left-handed motor performance indicated that some hemisphere-specific interference may have occurred during concurrent speech and manual motor activity; however, these results are complicated by the consideration that motor activity in the dominant hand is likely to be more automatic, thus requiring fewer attentional resources than the non-dominant hand. In addition, since it has been demonstrated that language and motor control are not completely lateralized in the brain, i.e., both hemispheres contribute to language and motor control of both sides of the body, the results of the present study indicate that the functional distance hypothesis does not fully explain the interference between speech motor control and other tasks in divided attention conditions. *Relevance to the current work*: The study gives insight into the complex nature of neural control during divided attention, and gives evidence that the functional distance hypothesis does not completely explain what occurs during such conditions.

Holmes, J. D., Jenkins, M. E., Johnson, A. M., Adams, S. G., & Spaulding, S. J. (2010). Dual-task interference: the effects of verbal cognitive tasks on upright postural stability in Parkinson's disease. *Parkinson's Disease, 2010*, 696492. doi:10.4061/2010/696492

Objective: The study was designed to evaluate the effect of divided attention on postural stability in individuals with Parkinson's disease (PD). *Method*: Twenty-four participants were included in the study: twelve with PD (M = 64.00 years) and twelve age-matched controls (M = 62.67 years). Participants with a high risk of falling were excluded from the study for safety reasons. The study was performed when participants were in the "on" phase of their PD medication. The researchers had the participants stand on a force plate during the experimental trials. The experimental trials included six 30 s trials, or two trials of three separate conditions. These conditions were standing with no secondary task, standing while counting, and standing while performing a conversational monologue. Three separate measurements of postural stability were taken during the trials. These measurements were the total length of the center of pressure (COP) path, the maximal medial lateral COP excursion range, and the maximal anterior posterior COP excursion range. *Results*: Condition and group interacted significantly, with the PD group performing differently than the control group for the three conditions. Each condition also differed from each other, with the monologue condition being the most difficult and causing the largest excursions from COP. *Conclusion*: The PD group showed less excursion from COP than the control group, which suggests that they prioritized the postural-task over the non-postural to such a high degree that they became rigid in their posture. This increased their risk for falls during divided attention conditions. *Relevance to the current work*: Both healthy participants and participants with PD experienced interference in a postural stability task performed under divided attention.

Kahneman, D. (1973). Basic issues in the study of attention. In *Attention and Effort* (pp. 1-12). Englewood Cliffs, NJ: Prentice-Hall, Inc.
Objective: This chapter serves as an introduction to theories of divided attention and a theory of mental effort. *Content*: The author discusses the strengths and weaknesses of two models of divided attention, the bottleneck structural model and the limited capacity model. The bottleneck structural model proposes that there is a certain point in cognitive processing that forces dual-task performance into a sequence, being unable to treat concurrent tasks in parallel. The limited capacity model proposes that the mind's capacity to attend to stimuli and to perform tasks is limited, and that divided attention causes an overdraft of this capacity, resulting in reduced performance on one or both tasks. *Relevance to the current work*: The divided attention models discussed in this chapter provide a foundation to understanding later refinements and models.

Ketcham, C. J., Dounskaia, N. V., & Stelmach, G. E. (2004). Age-related differences in the control of multijoint movements. *Motor Control, 8*(4), 422-436.
Objective: The study investigated how age affects multijoint movements. *Method*: The participants were divided into two age groups: younger adults (*M* = 27.8 years) and older adults (*M* = 68.1 years). The participants were seated at a table and had their trunk and wrist immobilized in order to focus the research observations on the interaction between the shoulder and elbow joints. The participants were asked to trace circles and ovals of varying sizes and orientations within a given template to the beat of a metronome. Different metronome frequencies were presented during the experimental trials. Each trial lasted 12 s, and each participant performed 60 trials. A camera system recorded the movement of light emitting diodes placed on the sternum, shoulder, elbow, and index fingernail. Electromyography of the biceps brachii, lateral head of the triceps, anterior deltoid, and posterior deltoid was used to evaluate their role in joint control. *Results*: Older adults moved their fingers more slowly than younger adults. Older adults maintained elbow excursion amplitude across frequencies, while younger adults increased elbow excursion amplitude with increases in frequency. Younger adults increased muscle torque at the elbow with frequency increases, while older adults did not increase muscle torque. Net torque of the multijoint system, which is the interaction between active muscle torque and the passive torque that one joint's movement places on the other joint in the system, was lower for older adults than younger adults. Older adults had less muscle activity than younger adults for all muscles measured. *Conclusion*: As frequency increased, both groups had reduced endpoint performance, which is the net result of a multijoint movement. However, the younger adults demonstrated greater coordination between the shoulder and elbow joints in timing and excursion amplitude. *Relevance to the current work*: The study describes physiological measures that decline with age.

Kinsbourne, M., & Hicks, R. E. (1978). Functional cerebral space: A model for overflow, transfer, and interference effects in human performance: A tutorial review. In J. Requin (Ed.), *Attention and Performance VII* (pp. 345-362). Hillsdale, NJ: Erlbaum.
Objective: This book chapter puts forward the functional distance hypothesis. *Content*: The authors review divided attention literature that improves on the single pool or channel hypothesis of division of attention and gives support to a hypothesis based on functional cerebral distance.

This hypothesis states that various processes are at different positions in an individual's functional cerebral space; processes that are performed by the same hemisphere or by the mirror body part are closer in cerebral space to each other. Conversely, processes performed by opposite hemispheres or by separate body parts are farther in cerebral space from each other. Performing two different tasks that are close in cerebral space from each other will lead to greater interference and greatly reduced performance; performing tasks that are far from each other in cerebral space will lead to less interference and performance that resembles single task conditions. The authors take the position that control of the voice, or language, is a left-hemisphere process, that spatiotemporal processing takes place in the right-hemisphere, and that motor control of each side of the body is contralaterally controlled. As such, according to the functional distance hypothesis, speech and concurrent movement of the right side of the body should interfere more than speech and left-sided movement. *Relevance to the current work*: The functional distance hypothesis is an important theme in researchers' attempts to explain the nature of divided attention.

McDowd, J. M., & Craik, F. I. (1988). Effects of aging and task difficulty on divided attention performance. *Journal of Experimental Psychology: Human Perception and Performance, 14*(2), 267-280.

Objective: The researchers evaluated how task complexity interacts with age in divided attention tasks. They also examined whether or not divided attention is different than overall task complexity. *Method*: The researchers performed two separate experiments. In experiment one, sixteen young (M age of 19.4 years) and sixteen older adults (M age of 69.0 years) participated. As a screening, the researchers used a vocabulary test to ensure both groups were equivalent in verbal ability. They asked the participants to perform two types of tasks (auditory and visual) at two levels of difficulty (easy and difficult). The tasks were performed separately in a single task condition, and together in various combinations in a divided attention condition. The researchers measured response times for correct responses. In experiment two, a group of young (M age of 21.0 years) and older adults (M age of 71.9 years for one of the tasks, 67.3 years for the other task) again participated. The participants performed two different visual tasks; one was considered easy and required less cognitive processing than the second, more difficult task. Both tasks could be performed at three different levels of complexity. The tasks were performed separately in a single task condition and with an auditory task in a divided attention condition. The researchers measured response times for correct responses as long as accuracy on the auditory task remained above 75%. *Results*: For experiment one, it was found that task difficulty increased reaction times for both age groups in the single task condition and the divided attention condition. It was also found that age was a significant factor in the divided attention condition, with older adults being negatively affected by the divided attention condition more than younger adults. Further, task difficulty increased this divided attention penalty in older adults. For experiment two, the researchers found mixed results; they found that age affected divided attention performance by increases in complexity in the difficult task more than the easy task. The effect of the divided attention condition for the easier task actually decreased with increases in complexity. *Conclusion*: Overall, the researchers determined that older adults are affected by divided attention more than younger adults, and that this effect increases as the difficulty of the tasks increases. They also found some evidence to support the idea that divided attention is a way of increasing task complexity, and so older adults may be affected by divided attention only to the extent that they are affected by task complexity. *Relevance to the current work*: The study shows that older adults are affected by divided attention more than younger adults when the complexity of the tasks is sufficiently difficult.

Menz, H. B., Lord, S. R., & Fitzpatrick, R. C. (2003). Age-related differences in walking stability. *Age and Ageing, 32*(2), 137-142.

Objective: The study was designed to compare walking stability between older adults and their younger counterparts. *Method*: Two groups of participants were recruited for the study: a younger group (M = 29 years) and an older group (M = 79 years). The older adults were determined to have a low risk of falling, based on their performance on a basic physiological profile with 75% accuracy at predicting falls. Participants were fitted with accelerometers at the head and waist levels. Each participant was directed to walk at a self-selected comfortable speed across a 20 m long uneven surface, and across a level surface. Accelerometer signals used for data analysis included velocity, steps per minute (cadence), average step length, step timing variability, acceleration root mean square (RMS), and the harmonic ratio of the two signals, which gives an idea into the smoothness of the walking pattern. *Results*: The older group had slower velocity, shorter step length, and greater step timing variability than the younger group. They also had lower acceleration RMS values at the waist for all three planes, and at the head for the vertical plane. Harmonic ratios were not affected by age. *Conclusion*: Although age was associated with an overall qualitative gait difference between the groups, the overall smoothness of gate was unchanged. The more conservative gait of older adults is believed to be a compensation for a decline in physiologic factors that contribute to balance, such as vision, depth perception, and ankle and quadriceps strength. *Relevance to the current work*: The study describes physiological measures that decline with age.

Müller, R.-A., Kleinhans, N., & Courchesne, E. (2003). Linguistic theory and neuroimaging evidence: An fMRI study of Broca's area in lexical semantics. *Neuropsychologia, 41*(9), 1199-1207. doi:10.1016/s0028-3932(03)00045-9

Objective: The neuroimaging study evaluated whether or not Broca's area is involved in semantic processing in addition to its known syntactic processing roles. *Method*: Participants included four females and five males between the ages of 21 and 30. All participants were right-handed native English speakers without a history of developmental, psychiatric, or neurologic disorders. The participants' brains were imaged with functional magnetic resonance imaging during the completion of experimental and control tasks. The experimental task was a semantic decision task. In this task, the participant was shown a noun and verb pair and was prompted by the instruction "Match?" to make a decision about whether or not the two were semantically related. Participants indicated their selection by pressing a button on a device held in their hands. The control task consisted of the participants being shown two chains of five lowercase or uppercase "x" characters, to which the participants were required to indicate whether or not the two chains were the "same." Processing of the images taken during the different trials allowed the researchers to localize the areas of activation unique to performance of the tasks. *Results*: The results of seven of the nine participants were included for the analysis and discussion. Activation during the semantic decision task involved primarily the superior frontal lobe (Brodmann areas 8 and 9), middle and superior temporal gyri (areas 21 and 22), and the inferior and middle frontal gyri (areas 44-46). This includes Broca's area (areas 44-45). Activation during the control task involved primarily the right superior and inferior parietal lobe (areas 7 and 40). *Conclusion*: Broca's area plays a role in semantic processing in addition to syntactic processing. *Relevance to*

the current work: The semantic decision task used in the study is the basis in format for the present study's linguistic and cognitive tasks.

Naveh-Benjamin, M., Guez, J., & Marom, M. (2003). The effects of divided attention at encoding on item and associative memory. *Memory & Cognition, 31*(7), 1021-1035.
Objective: The study evaluated the hypothesis that divided attention disrupts memory encoding at the level of association. *Method*: The researchers completed a series of five separate related experiments. Each experiment involved a different number of young adult undergraduate students. All of the experiments followed a dual-task divided attention design involving a memory task and either a visual or auditory continuous choice reaction time task. The memory task consisted of learning a series of word pairs for subsequent recall. The nature of the word pairs varied from experiment to experiment, with direct recall and associative recall being compared in each. Each task was performed separately in a focused attention condition and together in a divided attention condition. Performance on both tasks was recorded. *Results*: The overall results indicated that divided attention caused a general decline in memory performance compared to focused attention, but this decline was not greater for association tasks, as was expected. Divided attention affected both types of memory encoding tasks to a similar degree. *Conclusion*: The results are evidence against the associative deficit hypothesis, which states that association tasks should be more affected by divided attention than are direct recall memory tasks. On the contrary, divided attention seems to affect memory encoding in general, and this effect cannot be attributed to the association processes that take place during encoding. This divided attention effect on memory is similar, though not identical, to the aging effect on memory. *Relevance to the current work*: The study shows that divided attention affects memory. It also mentions similarities between divided attention and aging and their effects on memory.

Navon, D., & Gopher, D. (1979). Economy of the human-processing system. *Psychological Review, 86*(3), 214-255.
Objective: The purpose of the article is to introduce ways to model human task performance with economic principles and to discuss the multiple capacities model of divided attention. *Content*: The authors review divided attention theories and make connections to economic concepts and principles. Then they discuss a multiple capacities model of divided attention. This model differs from previous models in that it proposes that different tasks require different resources. This explains why interference in a dual-task paradigm differs depending on the nature of the tasks being performed. *Relevance to the current work*: The multiple capacities model is a major development in divided attention theory and is still relevant to current research.

Norman, D. A., & Bobrow, D. G. (1975). Data-Limited and Resource-Limited Processes. *Cognitive Psychology, 7*(1), 44-64.
Objective: The article examines the limited capacity model of divided attention and reviews experimental literature in support of it. *Content*: The limited capacity model puts forward the idea that there is a central and finite pool of attention resources available for performing the various processes or tasks that individuals may perform. When two processes, or tasks, are attempted simultaneously, they draw from the same pool of these attentional resources. If the combination of processing requirements surpasses the capacity of the central pool, then one or both tasks receives inadequate processing, resulting in decreased performance. Thus when two tasks are performed concurrently, they compete for attentional resources. However, not all tasks

require the same amount of resources. *Relevance to the current work*: The limited capacity model of divided attention is a foundation to understanding later theories of divided attention.

Oomen, C., & Postma, A. (2001). Effects of divided attention on the production of filled pauses and repetitions. *Journal of Speech, Language, and Hearing Research, 44*(5), 997-1004. doi:10.1044/1092-4388(2001/078)

Objective: This study was designed to determine whether or not filled pauses (filler words) and speech repetitions require significant attentional resources. *Method*: Eleven female and seven male young adults participated in the study. None had any previous speech, language, or hearing problems, nor any significant experience with extemporaneous speaking or piano playing. The participants were asked to perform two types of activities: a blind tactile perception task, in which they felt and identified figures made out of sand paper without being able to see them; and a picture-based story telling task, in which they were shown various pictures and asked to narrate a story based on them. The participants performed each task on its own, as well as both tasks together. The tactile perception task was performed on its own first, followed by the story telling task and the combined task in a counterbalanced order. The researchers scored the tactile perception task on the percentage of correct identifications. The speech samples from the story telling tasks were transcribed and then scored on the type and number of filled pauses and repetitions. They used two judges to ensure reliability of scoring for the story telling task. *Results*: The participants produced more filled pauses and more repetitions during the divided attention condition than during the speech-only condition. Only one subject did not utter more repetitions and filled pauses during the divided attention condition. The increase in repetitions was made up of sound/part-word repetitions and whole word repetitions, not phrase repetitions. Additionally, accuracy in the tactile perception task was lower during the divided attention condition, even though all the participants had practiced the task in an isolated condition first. *Conclusion*: The number of filled pauses and repetitions increased during the divided attention condition, indicating that filled pauses and repetitions do not rely on attentional resources and are therefore more automatic reactions. *Relevance to the current work*: This study demonstrates that speech is qualitatively affected by divided attention conditions. In addition, speech tasks may affect other tasks performed concurrently.

Talland, G. A. (1962). The effect of age on speed of simple manual skill. *The Journal of Genetic Psychology, 100*, 69-76.

Objective: The study was performed to examine the effect of age on performing a manual motor task in single task and divided attention conditions. *Method*: The participants in the study were grouped according to age: young, middle-aged, and older. All of the participants were male. There were 36 younger men in their early twenties, one group of 18 middle-aged adults (M = 52.8 years), and two groups of older adults (n = 18, M = 80.7 years; n = 17, M = 82.7 years). The participants were all healthy and free from color blindness and major vision or motor problems. The participants participated in experimental trials consisting of three different tasks, each performed on its own in a single task condition, as well as combined with one of the other tasks in a divided attention condition. The tasks were pressing a manual counter, using tweezers to transfer beads from one container to another, and using tweezers to remove one color of beads from out of a mixture of two colors of beads. The participants were instructed to perform the tasks as quickly as possible. Each trial lasted 60 s. Following practice trials, the participants completed the first bead task, the counter task, the counter task combined with the first bead task,

the second bead task, and the counter task combined with the second bead task. They then performed the sequence of tasks a second time. Data gathered included the number of beads transferred during each 60 s trial, and the number reached on the manual counter indicating the number of times it had been pressed. *Results*: The younger group performed more efficiently than the middle-aged group by moving more beads and pressing the counter more times in a set time during every task. The middle-aged group in turn performed more efficiently than the older group. The middle-aged and older groups were slowed in pressing the counter during divided attention conditions more than was the younger group. The same trend was true for the bead tasks in the divided attention condition. *Conclusion*: The younger adults were the most efficient at accomplishing the tasks in single task and divided attention conditions. This indicates that there is an association between increases in age and decreases in fine motor task performance. The differences between groups observed during divided attention conditions also indicate that there is an association between increases in age and decreases in divided attention performance. *Relevance to the current work*: Age has a significant effect on manual motor performance in single task conditions. Age is associated with a greater divided attention effect on manual motor performance in older men compared to younger men.

Troyer, A. K., & Craik, F. I. (2000). The effect of divided attention on memory for items and their context. *Canadian Journal of Experimental Psychology = Revue Canadienne de Psychologie Expérimentale, 54*(3), 161-171.
Objective: The study explored how divided attention conditions affect performance of memory tasks. *Method*: Three separate but related experiments were performed. All three used young adult participants. The participants performed three different types of memory tasks individually in a single task condition and combined with a digit-monitoring task in a divided attention condition. The memory tasks consisted of an item task, a color task, and a temporal-order task. For the item task, participants were presented with a list of words and were asked to recall them later. For the color task, sixteen different colors of cards, each with a different word printed on it, were presented, and the participants were asked to recall the color of card each word was printed on. For the temporal-order task, participants were presented with a series of sixteen white cards with different words printed on them and were asked to later recall the words in the order they had been presented. The digit-monitoring task involved an audio recording of spoken digits in random order, with the participants being asked to write down any string of three consecutive odd digits. Application of the divided attention condition was alternated between the encoding portion of the memory tasks only, the retrieval portion of the memory tasks only, and both the encoding and the retrieval portions of the memory tasks. *Results*: The divided attention condition during encoding had the effect of reducing performance on all of the memory tasks fairly equivalently. In addition, the divided attention condition during retrieval also reduced performance on all of the memory tasks fairly equivalently. However, when the divided attention condition was applied during encoding and retrieval of memory tasks, performance for each of the memory tasks was differentially affected. Performance on the temporal order task was reduced to a greater degree than was performance on the color and item tasks. *Conclusion*: The results indicate that both the encoding and retrieval processes of memory task performance are negatively impacted by divided attention conditions. This effect is magnified when attention is divided during both encoding and during retrieval. Certain types of context, namely temporal order, are affected more than others. *Relevance to the current work*: The study gives evidence that memory requires attention, and it is significantly affected by divided attention conditions.

Wickens, C. D. (1981). *Processing resources in attention, dual task performance, and workload assessment* (No. EPL-81-3/0NR-81-3). Champaign, IL: University of Illinois at Urbana-Champaign.

Objective: This technical report provides an overview of divided attention theories and their potential application for improving human performance of everyday work tasks. *Content*: The report reviews the literature explaining structural and capacity theories of divided attention performance. It also raises the possibility that rather than causing concurrent performance of two tasks in parallel, divided attention may instead force a rapid alternation of attention between the two tasks. The report refers to divided attention as "time sharing." It is argued that if this alternation were rapid enough, it would resemble parallel processing in manner and end result. The report also attempts to describe how divided attention theory can explain the performance of work when changes are introduced into the environment. *Relevance to the current work*: The report includes a discussion of the switching model of divided attention, which gives depth to the discussion about theories of divided attention.

Appendix B

Informed Consent

Consent to be a Research Participant

Introduction

This research study is being supervised by Christopher Dromey, a professor in the Communication Disorders Department at Brigham Young University. Graduate students from the BYU Communication Disorders program serve as research assistants with responsibilities in gathering, analyzing, and interpreting data. You are invited to participate in this study that was designed to help us understand speech performance while people are simultaneously doing other things. These tasks include linguistic, cognitive, or audible distractions. You were chosen to participate because you are a native English speaker with no history of speech, language, or hearing disorders. Equal numbers of men and women in three age groups will be invited to participate.

Procedures

If you agree to participate in this research study, the following will occur:

1. You will participate in a hearing screening
2. A lightweight measurement system will be placed on your head to measure your lip and jaw movements with small, flexible levers attached to the skin with double-sided tape
3. A microphone will record your speech
4. You will be given 3 different sets of sentences and asked to repeat them 15 times
5. In one part of the study you will be asked to repeat a sentence while you hear through headphones a comfortable level of white noise or the sound of several people speaking
6. You will perform a linguistic decision task to decide whether certain words belong together
7. You will perform a simple task with your hands (placing pegs into holes in a board)
8. You will perform a mental math task (deciding whether math statements are true or false)
9. You will repeat the sentences either in isolation, or while you are also doing the concurrent tasks listed above
10. Total time commitment will be 1 hour.
11. The study will take place in Room 106 of the Taylor Building on BYU campus.

Risks/Discomforts

There are minimal risks associated with participation in this study. It is possible that you may feel discomfort due to the head-mounted strain gauge system, or awkwardness from being audio recorded. If at any time, you feel uncomfortable, you may choose to excuse yourself from the study. All equipment used in this study has been used in previous research studies with no adverse effects.

Benefits

There will be no direct benefits to you. It is hoped, however, that through your participation, researchers may gain insight into speech production during the performance of concurrent tasks. This information will improve our understanding of divided attention activity (how the brain does more than one thing at a time), and it may provide future insight into how to better treat people with disordered communication.

Confidentiality

There will be no reference to your identification in paper or electronic records at any point during the research. An identification number will be used to organize the data we collect. The research data will be kept on a password-protected computer that is only accessible to the researcher and assistants.

Compensation

You will receive $10 for your participation; compensation will not be prorated.

Participation

Participation in this research study is voluntary. You have the right to withdraw at any time or refuse to participate entirely without jeopardy to your class status, grade, or standing with the university.

Questions about the Research

If you have questions regarding this study, you may contact Christopher Dromey at 801-422-6461, dromey@byu.edu for further information.

Questions about Your Rights as Research Participants

If you have questions regarding your rights as a research participant contact IRB Administrator at (801) 422-1461; A-285 ASB, Brigham Young University, Provo, UT 84602; irb@byu.edu.

Statement of Consent

I have read, understood, and received a copy of the above consent and desire of my own free will to participate in this study.

Name (Printed): _______________ Signature: _________________ Date: _________