2013-03-20

Effects of Syntactic Complexity on Speech Motor Performance

Kelsey Lewis Boyce
Brigham Young University - Provo

Effects of Syntactic Complexity on Speech Motor Performance

Kelsey L. Boyce

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

Christopher Dromey, Chair
Shawn Nissen
Ron Channell

Department of Communication Disorders

Brigham Young University

March 2013

ABSTRACT

Effects of Syntactic Complexity on Speech Motor Performance

Kelsey L Boyce
Department of Communication Disorders
Master of Science

This study evaluated the possible influence of linguistic demands on speech motor control by measuring articulatory movement stability during conditions of increasing grammatical complexity. There were 60 participants in three age groups: 20-30 years, 40-50 years, and 60-70 years, with equal numbers of men and women in each group. These speakers produced 10 repetitions of five different sentence or phrase conditions. These five conditions included two baseline measurements and three sentences of varying complexity. Each complexity condition had an MLU count of 23, word length of 17, syllable length of 25, and contained the phrase *open boxes of pompoms*. Complexity was measured by node-count and grammatical structure. Lower lip movements during production of the target phrase were used to compute the spatiotemporal index (STI), a measure of lip movement stability over 10 repetitions. It was predicted that STI would be lower (indicating greater stability) in the baseline and low complexity conditions. Comparison of complexity conditions against the baseline-counting condition demonstrated significant differences in the upper lip's STI, displacement, and velocity, as well as in vocal intensity. Speech motor differences between the grammatical complexity levels were minimal and could be attributed to several factors, such as speaking rate or semantic differences. An unexpected finding of this study was the influence of age on speech production. Participants from the 60 year-old group had significantly longer utterance duration, while those from the 20 year-old group had the highest lower lip and jaw STI values. These findings suggest that speech motor control matures even beyond young adulthood and that linguistic complexity does not appear to have a consistent effect on speech movement variables.

Keywords: divided attention, syntactic complexity, speech, language

ACKNOWLEDGMENTS

I would like to express appreciation to friends and family members who demonstrated optimism and provided support throughout the completion of this study, as well as professors who contributed their time and energy. Special gratitude goes out to all participants who donated their time to aid in this study, as well as the McKay School of Education for providing funding that went toward participant reimbursement and data analysis. Dr. Christopher Dromey provided countless hours of instruction, revision and support to assist me in reaching my goals. Dr. Shawn Nissen and Dr. Ron Channell also provided indispensable insight during the planning and revision stages of the study. Without the encouragement of these individuals, this experience would not have been nearly as enjoyable or educationally and personally fulfilling.

Table of Contents

List of Tables

List of Figures

List of Appendixes

Appendix Page

Description of Structure and Content

This thesis is presented in a hybrid format where current journal publication formatting is blended with traditional thesis requirements. The introductory pages are therefore a reflection of the most up to date university requirements while the thesis report reflects current length and style standards for research published in peer reviewed journals for communication disorders. Appendix A is composed of an annotated bibliography. Appendix B includes the informed consent forms for the speakers and listeners.

Introduction

Human communication involves an interaction between language planning and speech production. Past research has often focused on these aspects individually—the acquisition of either language (Brown, 1973; Ingram, 1989) or speech output (Shiller, Gracco, & Rvachew, 2010) —with much less research focused on the interaction between these two aspects of communication. Although divided attention research has been fairly limited in the area of speech and language, there has been increased interest and research on this topic in recent years. The present experiment examines the extent to which grammatical complexity may influence the movements of the articulators in speech production.

Human communication requires a division of neural processing resources across multiple functions, including hearing speech, processing auditory language, formulating a syntactically and semantically appropriate response, and instructing motor centers to produce correctly articulated speech. Communication co-occurs with other daily activities that require a division of attention to more than one task at a time. This observation has motivated several dual-task studies, which involve having participants complete two tasks independently of one another, followed by the performance of both tasks concurrently. This has been done in order to examine the effect that the tasks have on each other, which is usually referred to as *interference*. Previous research suggests that as increased demands are placed on an individual, performance in each task will decline (Dromey & Bates, 2005; Maner, Smith, & Grayson, 2000). In a concurrent visuomotor and speech task, where research participants produced speech and used a computer to click on a moving image, accuracy and speed of both tasks decreased significantly when compared to their independent completion (Dromey & Bates, 2005).

Theories have been proposed to explain how concurrent tasks requiring divided attention are performed. Single channel models suggest that there is one mechanism responsible for completing all tasks, and that performance decreases as increasing demands are placed upon it (Pashler, 1990). One such single channel model is the limited capacity theory, which proposes that there is a limited amount of brain capacity to be divided between concurrent tasks. Crystal (1987) applied the limited capacity theory to language and likened language processing capacity to a bucket. Each individual possesses a bucket that grows with age and is filled with linguistic demands. In this analogy, as increasing linguistic demands are placed on an individual, the bucket can overflow and cause a performance breakdown (Crystal, 1987). This limited capacity theory is supported by evidence where performance decreases during the concurrent completion of tasks (Dromey & Bates, 2005). Another model suggests that the brain processes only one stimulus at a time, giving attention to each item serially. This theory proposes a bottleneck effect during periods of increased demands (Kahneman, 1973).

These theories have been challenged on the basis of a person's ability to complete two tasks simultaneously (Wickens, 1976), and viewpoints have developed which oppose the limited capacity and bottleneck theories. One alternate theory is the multi-processor model, which suggests that there are multiple processors working concurrently. Thus, if the two tasks require separate processors, attention can be given to both simultaneously, and the tasks can be completed concurrently with little or no interference (McLeod, 1977).

An alternative explanation of dual-task performance is the functional distance hypothesis, or the idea that proximity of neural control centers can negatively affect one's ability to complete simultaneous tasks (Kinsbourne & Hicks, 1978). This hypothesis suggests that if tasks are controlled by proximal areas in the brain, such as two concurrent tasks controlled in the left hemisphere, they will interfere with one another more than if two concurrent tasks are controlled by anatomically distant areas of the brain. This theory would predict a difference between right- and left-sided limb performance during concurrent speech and language tasks due to the proximity of the left motor strip with the speech and language areas of the brain. Chang and Hammond (1987) tested this hypothesis with concurrent motor and speech tasks, finding that while interactions between the two occurred as expected, an explanation based on anatomical proximity was too simplistic. Dromey and Shim (2008) came to similar conclusions from their examination of the impact of right-handed versus left-handed activity on language. Because speech and language areas of the brain are anatomically close to the motor strip for right-sided limb control, it was hypothesized that these tasks would interfere with one another to a greater extent than during concurrent left-sided limb movement. The results of this concurrent motor, linguistic, and speech task suggested that placing high demands on one hemisphere results in more complex neural functioning than initially hypothesized. The results provided extremely limited support for the functional distance hypothesis.

During everyday conversational speech, both language processing and articulatory motor planning co-occur, along with auditory processing of language. Strand (1992) noted that many models of dual processing do not provide sufficient explanation of concurrent performance of motor control and language formulation. She discussed their co-emergence in the context of the way children acquire spoken language. Strand described the child's transition from holistic word learning and production to a stage in which individual sounds are cognitively represented by individual premotor plans. Therefore, as a child's brain matures, language and motor speech planning begin occurring as independent tasks that are completed simultaneously (Strand, 1992). Strand suggested that understanding the demands of both language and speech on processing resources may have clinical implications when working with individuals experiencing communication deficits (Strand, 1992). She suggested reducing language-processing demands when targeting speech, and reducing motor speech demands when language is the target of intervention.

The impact of linguistic complexity on speech production can be evaluated with several acoustic measures, including intensity and duration, as well as with measurements of articulator movement. Intensity, or loudness of speech, can offer insight into a speaker's increased or decreased vocal effort across varying complexities, while duration, or the length of time it takes to produce a sentence, would reveal whether language complexity influences the rate of production. The spatiotemporal index (STI) has been computed from articulatory kinematic records, and is a composite measure of spatial and temporal variability in lower lip movement sequences (Smith, Goffman, Zelaznik, Ying, & McGillem, 1995). It is used as an assessment of speech movement stability across multiple repetitions of a phrase. STI is most stable in a population of typical adult speakers, but deliberate alteration of speaking rate, whether speaking more slowly or more quickly, will cause articulatory movements to be more variable across repetitions (Kleinow, Smith, & Ramig, 2001; Smith et al., 1995). In previous studies it has been hypothesized that the influence of other aspects of communication, including language-processing demands, could lead to decreased speech motor stability.

Language complexity can be assessed in different ways. Some authors have examined which aspects of language influence complexity, or which aspect will have the greatest impact on an individual's ability to perform a concurrent task. Cheung and Kemper (1992) compared 11 metrics of complexity measurement in an attempt to determine the reliability of these measures in explaining age-group and individual differences in linguistic complexity, as outlined by

Kemper (1988). The researchers identified three main aspects of these metrics as mean length of utterance (MLU), complexity of grammatical constructions, and semantic content. The experiment applied these metrics to sentences with explicit complexity variations to compare how well the measurements indexed the complexity. Through their experimentation, mean length of utterance (MLU), amount of embedding, and type of embedding were found to be the biggest factors affecting sentence complexity. MacPherson and Smith (2013) examined how length contributes to complexity by separately testing the effects utterance length and the extent of embedding on speech motor performance. Their results revealed that altering sentence length led to significant changes in speech variability. Complexities of varying types of embedding have been defined with conjoined structures being least complex, and embedded structures as most complex (Givón, 1991). Another measurement of linguistic complexity is to complete a node count. A node count is a representation of all the words or phrases within a sentence. Nodes break down a sentence into all of its grammatical structures. Counting nodes is the closest representation of how humans parse out language, thus a node count is viewed as the 'most real' structural measure of complexity. As the number of nodes found in a sentence increases, the complexity of the sentence is said to increase (Szmrecsányi, 2004).

Because sentence length, type of embedding, and amount of embedding all independently impact syntactic complexity, they could interact with each other, causing increased complexity when combined. Due to this possibility, target utterances should be carefully designed, taking each of these complexity aspects into account. Maner et al. (2000) investigated the influence of linguistic complexity on speech motor performance in children and young adults and discovered that speech production is affected by changes in sentence complexity and length. Participants were recorded repeating an utterance in isolation, followed by that same utterance embedded in longer sentences of varying linguistic complexity. Based on the analysis of STI, increases in speech motor variability were noted for the longer, more grammatically complex sentences. There was a significantly lower STI during productions of the baseline utterance when compared to the productions of the utterance embedded into sentences. The authors attributed the change in STI to increased utterance length, increased linguistic complexity, or a combination of these factors. No significant differences were noted in STI values between the different levels of complexity (low and high) in the longer utterances. It could be speculated that the complexity conditions used in the Maner et al. study did not provide a great enough range of syntactic forms to cause changes in speech motor performance. Because the study by Maner et al. was limited by the confounding of length and complexity as well as the relatively narrow range of syntactic complexity conditions, additional research is warranted to determine if greater distinctions between complexity levels will affect the rate, intensity, and stability of speech motor performance.

The purpose of the current study is to determine how increasing syntactic demands will impact motor speech performance. Previous studies have shown that increasing demands in cognitive and motor skills will impact articulatory stability, but research regarding the impact of increasing linguistic complexity on speech production has been limited. Determining the impact of syntactic complexity on speech production will provide additional information regarding the attentional demands of linguistic complexity on speech. An understanding of interactions between speech and language in a typical population may also provide future insight into how disordered populations will function.

Method

Participants

Thirty male and 30 female native English speakers participated in this study. Participants belonged to one of three groups depending on age: Participants between the ages of 20 and 30 (*M* = 22.95, *SD* = 2.35) were grouped together, as well as participants between 40 and 50 (*M* = 45.25, *SD* = 3.67), and participants between 60 and 70 (*M* = 63.20, *SD* = 3.55). There were five men and five women in each age group. None of the participants reported any recent history of speech or language disorders, and each participant functioned daily without hearing amplification. Each participant gave written consent to participate in the experiment.

Instrumentation

Participants' lip and jaw movements were recorded using a head-mounted strain gauge system. To measure vertical lip movement, the strain gauge was connected at the midline of the participants' upper and lower lip vermillion border. The strain gauge system was also attached below each participant's chin to measure vertical jaw movement. The participants' speech was recorded with a microphone (AKG C420) mounted to the headset, and a sound level meter placed 100 cm from the mouth measured speech intensity. The signals from these transducers were digitized with a Windaq 720 (DATAQ Instruments, Akron, OH) analog/digital converter, with a sampling rate of 1 kHz for the kinematic and sound level meter channels, and 25 kHz (after 12 kHz low pass filtering) for the audio channel.

Procedures

All data were collected within a one-hour session. Each participant was randomly presented five utterances, each including the phrase *open boxes of pompoms*. Two of the utterances were baseline measurements, and three were carrier sentences of varying syntactic complexity. Baseline conditions consisted of the phrase *open boxes of pompoms* in isolation, as well as embedded within a rote counting task. Syntactic complexity of the carrier sentences was based on type of embedding, and included one sentence with phrasal elaboration, one conjoined sentence, and one sentence containing embedded clauses. Sentences were also normalized with respect to the number of nodes they contained, where a higher node count indicates greater grammatical complexity. The sentences were also normalized with respect to length, each sentence containing 17 words, 25 syllables, and an MLU count of 23. The baseline measure containing the rote counting task was normalized with respect to syllable length. Table 1 provides a complete list of utterances, including baseline-isolation, counting, elaboration, conjoining, and embedding conditions.

Table 1

List of stimulus items compared according to measures of length and complexity.

Number of words	Number of syllables	Number of morphemes	Node count	Grammatical structure	Stimulus item
--	--	--	--	Baseline-Isolation	Open boxes of pompoms
--	25	--	--	Baseline-Counting	One, two, three, four, five, six, seven, eight, open boxes of pompoms, one, two, three, four, five, six, seven, eight.
17	25	23	15	Phrasal Elaboration	The groups of new cheerleaders noticed the open boxes of pompoms lying on the locker room tables.
17	25	23	17	Conjoining	The cheerleaders were fighting about the open boxes of pompoms and each was grabbing the best ones.
17	25	23	20	Embedding	Cheerleaders sitting in the weight room ignored the open boxes of pompoms that were hitting the ground.

Participants were instructed to repeat each of the sentences 10 times at a comfortable speaking rate and loudness. The order of utterance complexity was randomized in order to minimize sequencing effects. The tasks were explained and practiced 5 times before data were collected in order to minimize learning effects.

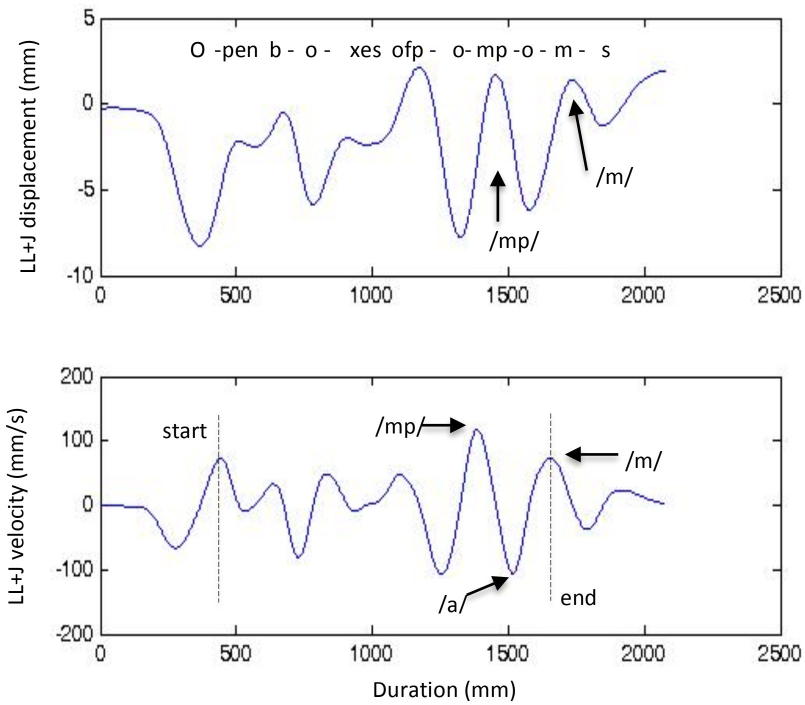

Figure 1. Displacement (upper panel) and velocity (lower panel) of the lower lip and jaw during one production of the target utterance. This kinematic record was segmented from the velocity peak of the closing movement of /p/ in *open* (start), and the closing /m/ movement in *pompoms* (end). The arrows mark the point measures used in the displacement and velocity measurements. LL+J= lower lip and jaw.

Data Measurement

The digital recordings of the lip and jaw movement were analyzed with custom MATLAB (MathWorks, 2012) routines. Measurements of speech production included utterance duration, sound pressure level (SPL), displacement, velocity, and several further measures derived from them.

Duration. Utterance duration was measured in ms each time the utterance, *open boxes of pompoms* was produced. Measurements started at the greatest velocity peak during the first closing bilabial movement of the word *open* and ended at the greatest velocity peak during the closing bilabial movement of the final /m/ of *pompoms* (see Figure 1). The duration was measured to assess possible changes in speaking rate as a function of grammatical complexity

Displacement and velocity. Displacement of the lower lip and jaw signal was measured for the bilabial closure during the second syllable of the word *pompom* from each production. The displacement of the closing gesture for the final /m/ was measured. See Figure 1 for details of the point measurement. The peak velocity from this movement was also measured. These measurements were made in order to better understand how the grammatical complexity might influence the magnitude of the articulatory movements.

Upper lip/lower lip correlation. A selected segment of the target utterance (see *displacement* and *velocity*) was used to measure the correlation between the upper lip and lower lip displacements. This quantified the phase relationship between the upper and lower lip movements; a correlation of -1 would indicate that the upper and lower lip moved in exact opposition to each other. This measure was used to examine whether increasing linguistic demands would influence the coordination of speech movements.

Spatiotemporal index (STI). Ten segmented displacement waveforms (see *duration*) were normalized with respect to time and amplitude for each condition. Amplitude was normalized by subtracting the mean and dividing by the standard deviation of each displacement. Time was normalized by Fourier analysis and re-synthesis to perform a linear interpolation, as described by Kleinow et al. (2001). Because no two repetitions of target utterances are produced identically in terms of duration and mean amplitude, normalization of the waveform is necessary to allow for statistical analysis of multiple productions. The STI was calculated by taking the sum of the standard deviations from 50 equally spaced points along the normalized waveforms

(Smith et al., 1995). This allowed the STI to measure consistency of speech articulation over multiple repetitions, where a smaller number reflects lower variability.

Velocity peaks. After the velocity record of the segmented utterance (see *duration*) was generated (the first derivative of the displacement), the number of velocity peaks found within the utterance was computed by counting the zero-crossings in the acceleration record (the second derivative of the displacement). Fewer velocity peaks are generally associated with more stable speech, and it was hypothesized that this measurement would be influenced by changes in linguistic complexity.

SPL. The mean SPL for the segmented utterance (see *duration*) was calculated. This measurement was made in order to learn whether grammatical complexity would influence vocal intensity.

Statistical Analysis

Univariate repeated-measures ANOVA tests were used to evaluate the statistical significance of differences in the dependent variables across the different levels of linguistic complexity. Because initial testing revealed no differences in the performance of men and women, the data for both were pooled for further analysis. An initial repeated-measures ANOVA included each of the five complexity levels, comparing each complexity against the baseline-isolation condition. This testing was performed to learn whether the length and complexity might interact, as was suggested by Maner et al. (2000). After interpretation of these results, a four-level repeated-measures ANOVA test, excluding the baseline-isolation condition, was completed to compare each linguistic complexity against the counting task. This testing was done to evaluate the effect of linguistic complexity without the influence of utterance length. Significant within-subjects effects for linguistic complexity or between-subjects effects for age were examined with a Tukey HSD post hoc test.

Results

At least one listener confirmed the correct production of each of the 10 target phrase repetitions included in the analysis. One participant failed to produce 10 acceptable repetitions during the rote-counting condition, and the data for this speaker and condition have been excluded from analysis.

Initial ANOVA Including Baseline-Isolation

A comparison of each complexity condition against the baseline-isolation condition revealed that productions of the baseline-isolation condition had significantly longer durations than all other conditions, greater displacement and velocity when compared against embedding and counting, more velocity peaks, and a greater intensity (measured in dB). No significant differences were found in STI when comparing the baseline-isolation condition with any of the other conditions. The baseline-isolation condition (the phrase *open boxes of pompoms* without any words before or after it) was excluded from subsequent analyses because it was substantially shorter than the other four sentences. In the remaining analyses, each complexity condition was compared against the counting baseline condition.

Descriptive statistics for the kinematic and intensity variables for each level of sentence complexity are reported in Table 2. The baseline-isolation condition (*open boxes of pompoms* spoken on its own) was excluded from this table in order focus on the effects of grammatical complexity without the potentially confounding effect of utterance length.

Table 2

Descriptive statistics for the kinematic and intensity measures in each complexity condition.

Condition	Age	1- Counting *M*	1- Counting *SD*	2-Elaboration *M*	2-Elaboration *SD*	3-Conjoining *M*	3-Conjoining *SD*	4- Embedding *M*	4- Embedding *SD*
Duration (ms)	20s	1122.3	65.9	1156.4	75.4	1116.1	55.5	1130.4	58.5
	40s	1161.2	91.5	1154.1	84.2	1149.7	79.7	1145.7	74.7
	60s	1278.5	99.0	1242.0	89.2	1248.0	85.8	1223.5	85.4
LL displacement (mm)	20s	8.79	1.93	8.95	1.68	9.01	1.66	8.83	1.75
	40s	9.08	1.76	9.28	2.30	9.29	1.98	9.08	2.07
	60s	9.53	3.19	9..67	3.19	10.07	3.57	9.35	2.84
LL velocity (mm/s)	20s	129.30	25.96	131.80	25.77	133.19	23.84	131.84	26.40
	40s	130.15	26.67	132.47	31.82	133.39	31.43	130.24	28.01
	60s	124.68	43.32	130.25	43.07	134.22	49.87	127.57	41.93
UL/LL Correlation	20s	-0.57	0.24	-0.61	0.25	-0.60	0.25	-0.62	0.24
	40s	-0.37	0.48	-0.39	0.48	-0.36	0.51	-0.41	0.50
	60s	-0.28	0.43	-0.26	0.47	-0.28	0.46	-0.32	0.45
STI UL	20s	12.76	3.96	13.17	3.92	11.88	4.02	11.89	2.05
	40s	12.60	3.38	11.25	2.53	11.36	2.92	11.44	2.96
	60s	12.75	5.02	11.95	4.58	10.68	3.95	11.54	5.52
STI LL	20s	18.84	3.96	13.17	3.92	11.88	4.02	11.89	2.05
	40s	16.70	4.68	15.37	4.38	16.20	5.90	16.12	6.01
	60s	16.06	4.85	15.56	4.65	14.00	4.60	15.90	5.99
STI J	20s	13.96	3.25	14.23	2.81	13.60	3.44	14.39	3.09
	40s	11.65	3.78	10.87	2.46	10.88	2.77	11.17	2.29
	60s	13.21	3.40	12.33	1.86	11.52	3.78	11.73	2.72
STI LL+J	20s	13.03	2.57	13.45	2.29	12.87	3.56	13.08	1.90
	40s	12.09	3.55	11.17	2.04	11.06	2.69	11.51	2.30
	60s	12.35	2.41	12.16	2.01	11.03	2.51	11.64	2.71
Velocity peaks	20s	5.62	0.36	5.84	0.40	5.76	0.37	5.69	0.41
	40s	5.67	0.42	5.65	0.36	5.71	0.48	5.75	0.44
	60s	6.07	0.48	5.98	0.43	5.99	0.44	5.80	0.35
dB SPL at 100 cm	20s	56.06	3.24	57.26	2.69	57.15	2.97	56.81	3.49
	40s	53.75	4.21	54.74	3.90	54.63	4.40	54.07	3.85
	60s	55.84	5.39	56.20	5.47	56.51	5.84	55.91	5.24

Note. Duration= utterance duration; LL= lower lip; UL= upper lip; STI= spatiotemporal index, J= jaw

Duration

No significant differences were found in duration across the different complexity conditions. The interaction of age with complexity was significant, $F(2,57) = 2.405$, $p = .044$. In the 20s group, duration increased between the counting and elaboration conditions, whereas the 40s and 60s groups demonstrated an overall decrease in duration as complexity increased. Post hoc analysis determined that participants in the 60s group had significantly longer duration of the target utterance across all conditions than participants from the 20s or 40s groups, as shown in Figure 2.

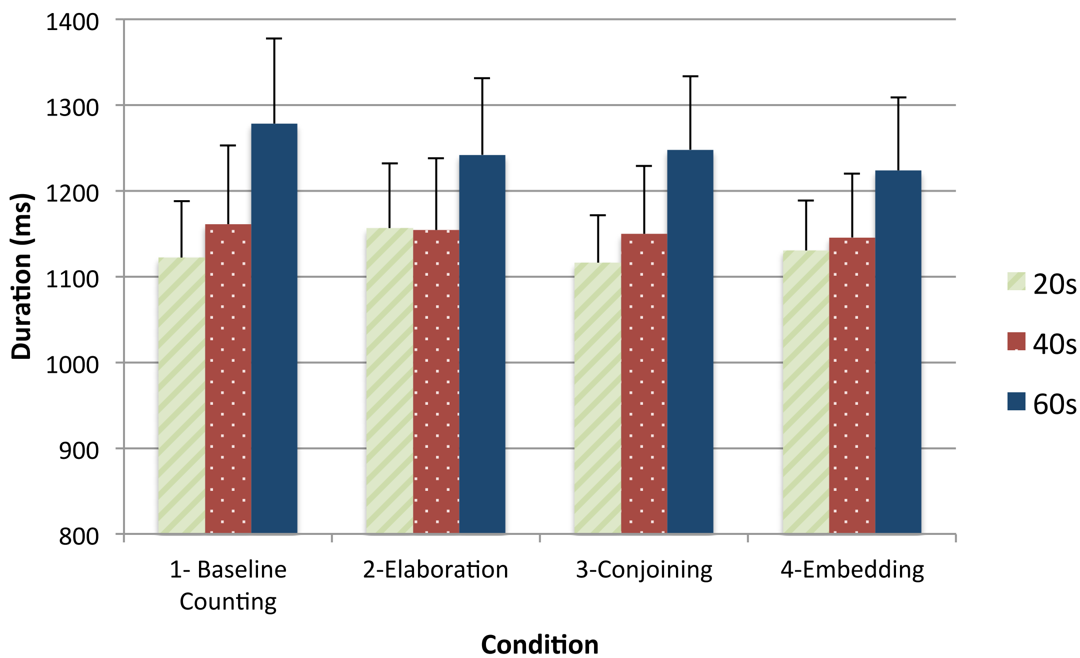

Figure 2. Utterance duration across the conditions, grouped according to condition.

Displacement and Velocity

Differences in displacement and velocity for the bilabial closing gesture (see Figure 1), were significant when comparing the counting condition with the conjoining complexity. The movements in the conjoining condition involved greater displacement, $F(57,1) = 6.847$, $p = .011$, and higher velocity, $F(57,1) = 8.534$, $p = .005$. No differences by age were significant.

Upper lip/Lower lip Correlation

No significant differences were found across the complexity conditions and no interactions between age and complexity were significant. There was a significant difference in the 20s and 60s correlations, with the 60s group having weaker correlations between the upper and lower lip, $F(57,2) = 3.308$, $p = .044$.

STI

When comparing the level one-counting condition with the conditions of varying complexity, significant differences were found in the STI of the upper lip (STI-UL) for the conjoining condition, $F(56,1) = 10.814$, $p = .002$, and for the embedding condition, $F(56,1) = 6.236$, $p = .015$, with the least stable movements found in the counting condition..

Inspection of the data indicates a general trend for STI to be higher in the 20s group, lowest for the 40s group, with the 60s age group in between those two, as seen in Figure 3. These differences were significant between the 20s and 40s groups for STI of the jaw, $F(56,2) = 7.411$, $p = .001$, and STI of the lower lip and jaw combined, $F(56,2) = 4.201$, $p = .020$.

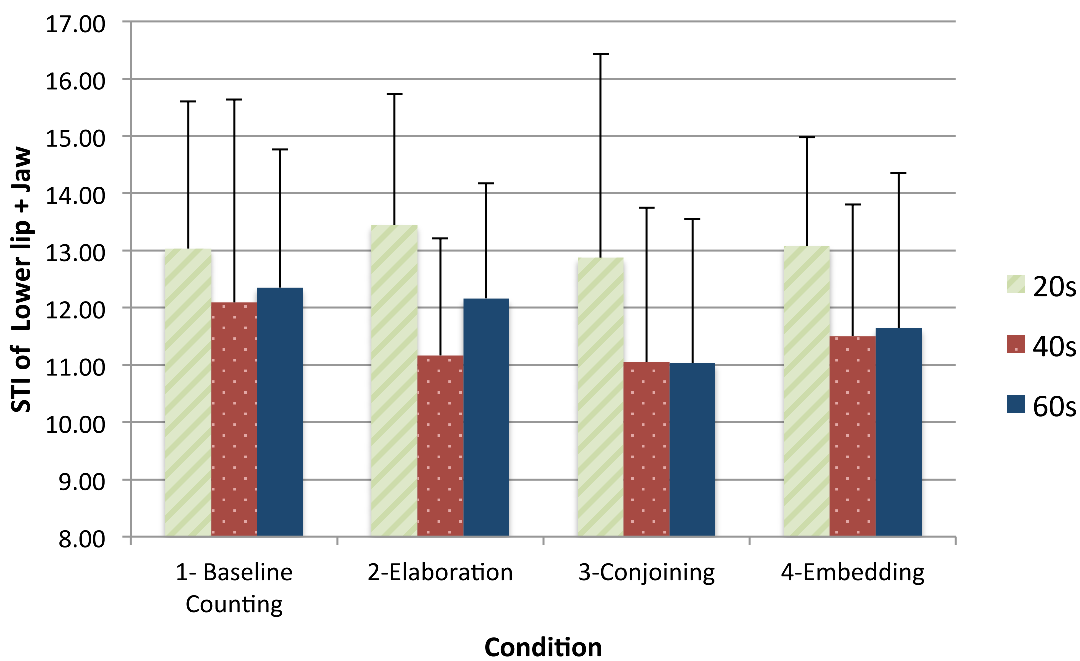

Figure 3. Lower lip and jaw spatiotemporal index across the conditions, grouped according to condition

Velocity Peaks

A count of velocity peaks within the target utterance was performed. No significant differences were found across grammatical complexity levels, but significant interactions were found for age and complexity, $F(57,2) = 3.560$, $p = .003$. When comparing the counting condition to the elaboration condition, the 20s group increased in the mean number of peaks per utterance, where the 40s and 60s groups decreased in mean number of peaks. Comparison of the counting condition to the embedding condition demonstrated an increase in the number of velocity peaks in the 20s and 40s age groups, while the 60s age group decreased the number of peaks, as seen in Figure 4. There were no significant differences between the age groups.

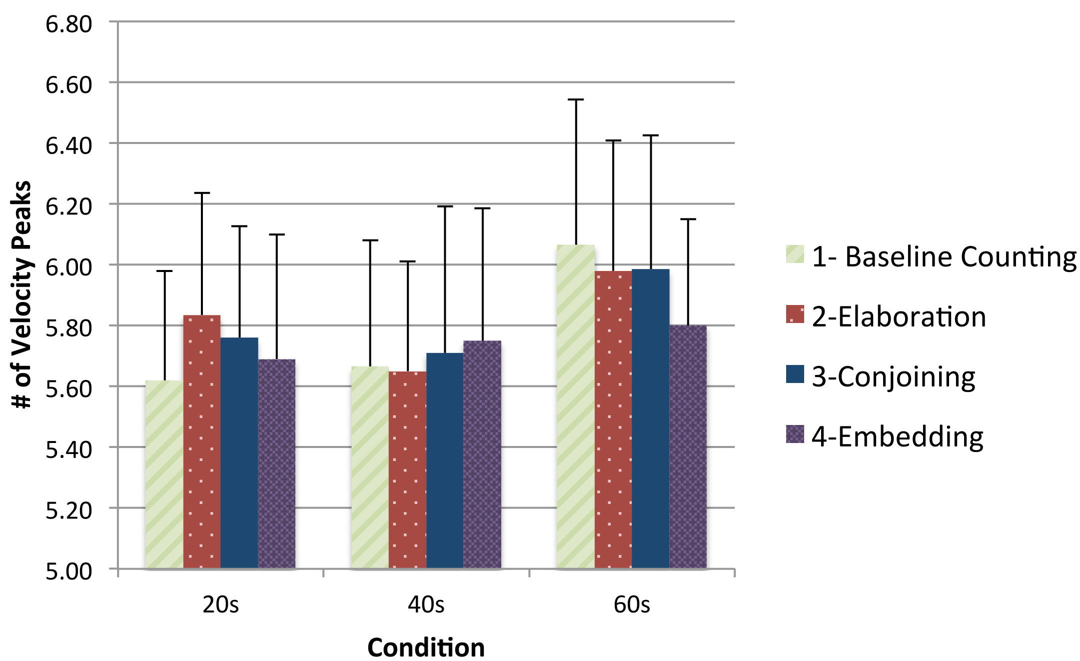

Figure 4. Velocity peaks across the conditions, grouped according to age

SPL

The intensity with which speakers produced the counting condition was significantly lower than all other conditions, $F(56,1) = 11.604$, $p < .001$. No interactions between age and complexity were found for intensity level, and no age effects were significant.

Discussion

This study was designed to investigate the potential effects of increasing linguistic complexity on articulatory performance. Due to the cognitive demands placed on the central nervous system during speech and language production, it was anticipated that increased linguistic complexity might reduce the cognitive resources allocated to producing stable speech movements. The results did not offer convincing evidence of increasing articulatory instability due solely to changes in linguistic complexity. The initial statistical analysis, which included all five complexity levels, revealed significant differences in the dependent measures across the speaking conditions. Significant differences were detected between the baseline-isolation condition and each condition of varying complexity. However, because no differences were found between the complexity levels themselves, the significant results suggest that length, rather than grammatical complexity per se, was responsible for the effect; this had previously been speculated by Maner et al. (2000), Kleinow and Smith (2006), and MacPherson and Smith (2013). Because length appears to have confounded any linguistic complexity effect, it cannot be concluded that the differences revealed in this analysis were due solely to complexity. This statistical analysis confirmed that length of utterance did have an effect on speech movements. The remaining discussion examines the results of the four-level repeated-measures ANOVA, including the counting condition through the embedding condition, without the baseline-isolation condition.

Analysis of the four complexity levels of equal length revealed that the only significant differences in articulatory stability across complexity conditions were for the STI of the upper lip across the counting, conjoining, and embedding conditions. STI of the upper lip was significantly higher, indicating less stability, for the counting condition, which was hypothesized to be the least complex of the utterances, requiring the smallest linguistic demands, and having the least potential effect on articulatory stability.

Abbeduto (1985) examined the effect linguistic complexity had on speech stability by measuring durational changes and variability across repetitions of a phrase. His results showed that adult speech variability increases as a sentence becomes more linguistically complex. Maner et al. (2000) also predicted increasing variability as complexity increased, but could not confidently attribute the results to syntactic changes due to length interference. In a study by Kleinow and Smith (2000), the authors noted no significant differences in STI of typical adults across linguistic complexity levels. The current results contrasted with each of these previous studies, with a simple sentence resulting in higher STIs than any other level of sentence complexity. It can thus be speculated that these results may not have been due solely to changes in linguistic complexity but that alternative explanations should be considered.

Potential Influences on Speech Stability

The following discussion will examine the possible effects that speech rate, prosodic changes, age, or changes in semantic demands may have had on STI,

STI and speed. In the current study, it was found that the counting task had higher STI levels, lower intensity levels, smaller displacement, and lower velocity levels than the sentences with higher complexity. There were no significant differences across elaboration, conjoining, or embedding complexities when compared against each other, so it can be assumed that the counting condition was intrinsically different from the others, and the differences in the dependent measures cannot be confidently attributed to linguistic complexity. One possible explanation for these results may be the speed with which individuals completed the counting condition. Automatic speech tasks, including rote counting, can be completed at a faster pace than linguistically demanding tasks, such as reading and producing a more complex sentence. Since the counting task alone included automatic speech, and significant differences in STI were found when comparing this condition against the others, it could be speculated that increasing the speech rate may have caused a decrease in motor speech stability. However, this explanation would be inconsistent with the findings of previous studies. Smith et al. (1995) found that that a slower speaking rate resulted in higher STI, or less stable speech movements, while an increase in speech rate had no significant effect on STI. Kleinow and Smith (2006) also found that complex sentences were associated with a slower rate and greater speech movement variability.

In the current study, no clear interaction between duration and STI was observed, but trends indicated a pattern that was different from that of Smith et al. (1995). Members of the 60 year old group demonstrated significantly longer utterance duration than the 20 year olds, but also demonstrated more stable speech than the 20 year olds. Comparing the current data with the findings of Smith et al. (1995) indicates that speech rate changes alone may not account for differences in speech stability. The differences in the findings of the two studies may implicate other factors, such as the interaction between duration, velocity, and displacement. Smith et al. (1995) reported that alterations in speech rate cause disproportional scaling in the relative timing of peak velocities with regard to the total movement time of an utterance, and data from the current study suggest that speech rate may also impact overall peak velocity and displacement values. Increased speech rate may lead to decreased displacement of the articulators, and therefore, smaller velocity peaks.

STI and semantic factors. Another possible explanation for the higher STI and lower intensity for the counting condition is the semantically atypical nature of the counting task. Each of the other complexity conditions involved a sentence structure that could be found in normal conversation, but the counting condition entailed the semantically abnormal task of switching between automatic speech and semantically meaningful speech. Such a semantic switch might have had an impact on the overall cognitive demands of the task, which could add to the change in motor speech performance. The demands placed on the system during the unnatural task of semantic switching within an utterance could be a potential source of the STI and intensity differences between productions of level one-counting condition and the other complexity conditions.

STI and age. There were significant differences in speech motor stability across age groups. It was anticipated that a highly practiced and skilled motor task, such as speech production, would have fairly low levels of variability once individuals have reached adulthood. Analysis of STI results, however, indicated that the 20s group had significantly higher variability in their speech when compared to the 40s and 60s groups. Many previous studies have examined the effect of age on speech movements, but have not looked at differences that occur after adulthood (Kleinow & Smith, 2006). Green, Moore, and Reilly (2002) found that when comparing ages ranging from infancy (11-13 months) to adulthood (ages 27-35), children at the age of six produced adult-like upper lip, lower lip, and jaw movements during productions of /mama/ /papa/ and /baba/. These findings suggest that by the age of six, simple bilabial patterns had developed to near-adult levels. Maner et al. (2000) examined the effect of age on speech stability by comparing 5 year-old children with young adults (ages 20-25). This study found that there were still significant differences between adult and child STIs across conditions of greater linguistic complexity than just repetition of CVCV syllables. These two studies would suggest that as age increases, speech movements become more stable, possibly due to repetition and length of time mastering speech motor movements. Neither of these experimental designs, however, included individuals between the ages of six and 20 and neither examined participants within a range of ages reaching into later adulthood. Data from the current study suggest that the control of consistent articulatory movements continues to develop and change, even after young adulthood. Additional research regarding adolescent and young adult motor speech productions could provide insight into the maturation of the speech mechanism across the lifespan.

Other age effects. Utterance duration was significantly longer in the 60s group when compared to productions by the other two age groups. Although no other factors were significant, the longer utterance durations coincided with higher displacement and lower velocity measures, suggesting that the longer durations from the 60s group were necessary to complete the larger articulatory movements. The duration interaction involving age and complexity conditions, where the 20s group had longer durations during the elaboration task than in the counting condition, could be attributed to the simplicity of the task of repetitively counting to eight. In the elaboration condition, a less automatic speech task with greater linguistic complexity, greater cognitive and attentional demands would be placed on the participants, and they would be unable to produce the utterance as quickly as they had produced the counting condition. Because only the 20s group demonstrated a shorter duration during the counting condition, it could be speculated that the 20s group allocated fewer attentional resources to the counting condition due to its automatic nature, while participants from the 40s and 60s groups gave equal attention across conditions.

Age and complexity also had a significant interaction when measuring the number of velocity peaks. As with duration, the 20s group showed an increased number of velocity peaks across repetitions of the elaboration phrase when compared with the counting condition. The 40s and 60s groups both demonstrated the opposite effect, with fewer velocity peaks in the elaboration condition when compared with the counting condition. A similar explanation of attention to the task could potentially be applied to these results. As discussed previously, the 20s group demonstrated the shortest duration during the counting condition, perhaps due to the lack of attention paid to the automatic speech task. This change in duration may have had an influence on the number of velocity peaks. According to Smith et al. (1995), shorter duration might be associated with lower variability in speech movement patterns. Greater stability is also associated with fewer velocity peaks, so the interaction between age and complexity in the number of velocity peaks could be explained by suggesting that duration, velocity peaks, and stability are all interconnected and that each impacts the others during speech production.

A perplexing finding of this study was the observation that upper lip and lower lip correlation differed across the age groups. The 20s group had a significantly stronger negative correlation between the upper and lower lips than the 60s group. In previous studies (Dromey & Bates, 2005; Dromey & Benson, 2003), although not statistically significant, stronger upper and lower lip correlation was associated with slightly lower STI values, or more stable speech. The current results were not consistent with those findings; the 20s group demonstrated the highest STI values, with the strongest negative correlation. This suggests that while the coordination of upper and lower lip movements appeared stronger for the young adults, the consistency of the movements across repetitions was lower, suggesting that different mechanisms may regulate coordination and consistency.

Prosodic variation. The sentence context in which the target phrase *open boxes of pompoms* was produced may have influenced the results. As the target utterance was placed within different syntactic structures, a variety of stress, pause, and intonation patterns were naturally present. These incidental changes in prosody or speech rhythm might account for some of the differences in STI of the upper lip between the counting condition and conjoining or embedding conditions. Sentences were not normed with respect to the number of natural pauses within them, and the target utterance was in some cases nearer the beginning and in others the end of the sentence. It could be speculated that these factors had an effect on the way in which the target utterance was spoken. Coarticulation could also have played a role in the significant differences observed across complexity levels. For instance, more complex motor movements in the words leading up to the target phrase might have caused more hesitation, greater emphasis, or slowed rate at the target utterance itself.

Ecological Validity

Few significant differences in articulatory stability were found across levels of linguistic complexity, suggesting that in this particular study, linguistic complexity might not have placed sufficient demands on the available resources to negatively influence articulatory performance. It could be speculated that this finding was due to limitations of the experimental design. In order to use STI as a dependent measure, which required 10 repetitions of a single utterance, a structured experimental design was necessary. The repetitive nature of the stimuli, however, resulted in utterances that were not representative of typical conversational speech. The most natural form of speech production is found during everyday conversation, where linguistic formulation and speech planning occur simultaneously. An experimental design including spontaneous conversational samples would limit the independent control of aspects of the target utterances, including length, syntax, or semantics, that were important to standardize in addressing the main research objectives of the study. The structure of the current experimental design provided a way of measuring and analyzing specific aspects of language and speech; however, no linguistic creativity was required of the participants of this study, and the task was not representative of typical language and speech behavior.

Conclusion

In summary, the findings from the present study support the idea that articulatory stability increases with age, but the data suggest that the age at which the neural motor planning system reaches full maturity may be after young adulthood. Although few significant results were attributed to the changes in linguistic complexity across conditions, the experimental utterances may not have been reflective of the processing demands encountered in everyday language and speech interactions. Future work measuring linguistic and motor interactions through a more natural task could lead to increased understanding of how the two affect each other in typical conversation.

References

Abbeduto, L. (1985). The effects of linguistic complexity on children's and adults' motor programming of speech. *Language and Speech, 28*(4), 361-375. doi:10.1177/002383098502800402

Barlow, S. M., Cole, K. J., & Abbs, J. H. (1983). A new head-mounted lip-jaw movement transduction system for the study of motor speech disorders. *Journal of Speech and Hearing Research, 26*, 283-288.

Brewer, G. A., Ball, B. H., Knight, J. B., Dewitt, M. R., & Marsh, R. L. (2011). Divided attention interferes with fulfilling activity-based intentions. *Acta Psychologica, 128,* 100-105. doi:10.1016/j.actpsy.2011.05.011

Brown, R. (1973*). A first language: The early stages*. Cambridge, MA: Harvard University Press.

Carnahan, H., Elliott, D., & Lee, T. D. (1986). Dual-task interference between speaking and listening and a unipedal force production task. *Neuropsychologia, 24*, 583-586. doi:10.1016/0028-3932(86)90102-8

Chang, P., & Hammond, G. R. (1987). Mutual interactions between speech and finger movements. *Journal of Motor Behavior, 19*, 265-274.

Cheung, H., & Kemper, S. (1992). Competing complexity metrics and adults' production of complex sentences. *Applied Psycholinguistics, 13*, 53-76. doi:10.1017/S0142716400005427

Crystal, D. (1987). Towards a 'bucket' theory of language disability: Taking account of interaction between linguistic levels. *Clinical Linguistics & Phonetics, 1*(1)*,* 7-22.

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

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,* 1234-1246. doi:10.1044/1092-4388(2003/096)

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,* 446-454. doi:10.1080/17549507.2010.485649

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*, 1171-1182. doi:10.1044/1092-4388(2008/06-0221)

Friedman, A., Polson, M. C., & Dafoe, C. G. (1988). Dividing attention between the hands and the head: Performance trade-offs between rapid finger tapping and verbal memory. *Journal of Experimental Psychology: Human Perception and Performance, 14*, 60-68. doi:10.1037/0096-1523.14.1.60

Givón, T. (1991). Markedness in grammar: distributional, communicative and cognitive correlates of syntactic structure. *Studies in Language, 15*(2), 335-370. doi:10.1075/sl.15.2.05giv

Green, J. R., Moore, C. A., & Reilly, K. J. (2002). The sequential development of jaw and lip control for speech. *Journal of Speech, Language, and Hearing Research, 45*(1), 66-79. doi:10.1044/1092-4388(2002/005)

Ho, A. K., Iansek, R., & Bradshaw, J. L. (2002). The effect of a concurrent task on Parkinsonian speech. *Journal of Clinical and Experimental Neuropsychology, 24*, 36-47.

Ingram, D. (1989). *First language acquisition.* Cambridge: Cambridge University Press.

Kahneman, D. (1973). *Attention and effort.* Englewood Cliffs, NJ: Prentice Hall.

Kemper, S., Herman, R. E., & Liu, C. (2004). Sentence production by young and older adults in controlled contexts. *Journal of Gerontology, 59B*(5), 220-224. doi:10.1093/geronb/59.5.P220

Kemper, S., & Rash, S. (1988). Speech and writing across the life-span. In M. M. Gruneberg, P. E. Morris, & R. N. Sykes (Eds.), *Practical aspects of memory: Current research and issues* (pp. 107-112). Chichester, U.K.: Wiley.

Kinsbourne, M., & Hicks R. E. (1978). Functional cerebral space: a model for overflow, transfer, and interference effects in human performance. A tutorial. In J Requin (Ed.), *Attention and performance VII* (pp. 345-362). Hillsdale, NJ: Erlbaum.

Kleinow, J., & Smith, A. (2000). Influence of length and syntactic complexity on the speech motor stability of the fluent speech of adults who stutter. *Journal of Speech, Language, and Hearing Research, 43*(2), 548-559.

Kleinow, J., & Smith, A. (2006). Potential interactions among linguistic, autonomic, and motor factors in speech. *Developmental Psychology, 48*, 275-287. doi:10.1002/dev.20141

Kleinow, J., Smith, A., & Ramig, L. O. (2001). Speech motor stability in IPD: Effects of rate and loudness manipulations. *Journal of Speech, Language, and Hearing Research, 44*, 1041-1051. doi:10.1044/1092-4388(2001/082)

Leclercq, M. (2002). Theoretical aspects of the main components and functions of attention. In M. Leclercq & P. Zimmermann (Eds.), *Applied neuropsychology of attention: Theory, diagnosis and rehabilitation* (pp. 3-55). New York: Psychology Press.

MacPherson, M. K., & Smith, A. (2013). Influence of sentence length and syntactic complexity on the speech motor control of children who stutter. *Journal of Speech, language, and Hearing Research, 56*, 89-102. doi:10.1044/1092-4388(2012/11-0184)

Maner, K. J., Smith, A., & Grayson, L. (2000). Influences of utterance length and complexity on speech motor performance in children and adults. *Journal of Speech, Language, and Hearing Research, 43*, 560-573.

MathWorks. (2011). MATLAB (Version 2011b) [Computer software]. Natick, MA: Author.

Mcleod, P. (1977). A dual task response modality effect: Support for multiprocessor models of attention. *Quarterly Journal of Experimental Psychology, 29*(4), 651-667.

Pashler, H. (1990). Do response modality effects support multiprocessor models of divided attention? *Journal of Experimental Psychology: Human Perception and Performance, 16*(4), 826-842. doi:10.1037//0096-1523.16.4.843

Shiller, D. M., Gracco, V. L., & Rvachew, S. (2010). Auditory-motor learning during speech production in 9-11-year-old children. *Public Library of Science Journals, 5*(9), 1-9. doi:10.1371/journal.pone.0012975

Smith, A., Goffman, L., Zelaznik, H. N., Ying, G., & McGillem, C. (1995). Spatiotemporal stability and patterning of speech movement sequences. *Experimental Brain Research, 104,* 493-501. doi:10.1007/BF00231983

Strand, E. A. (1992). The integration of speech motor control and language formulation in process models of acquisition. In R. Chapman (Ed.), *Process in language acquisition and disorders* (pp. 86-107). St. Louis: Mosby Year Book.

Szmrecsanyi, B. M. (2004). On operationalizing syntactic complexity. *Journées internationales d'Analyse statistique des Données Textuelles, 7*, 1031-1038.

Wickens, C. D. (1976). The effects of divided attention on information processing in manual tracking. *Journal of Experimental Psychology: Human Perception and Performance, 2*(1), 1-13. doi:10.1037/0096-1523.2.1.1

Appendix A

Annotated Bibliography

Abbeduto, L. (1985). The effects of linguistic complexity on children's and adults' motor programming of speech. *Language and Speech, 28*(4), 361-375. doi: 10.1177/002383098502800402

Objective: This study examined the role that syntax and semantics play in motor speech planning. *Method:* There were three groups: 5 year olds, 8 year olds, and adults. Each group consisted of 12 individuals. Participants were instructed to repeat sentences of varying complexity at a maximum rate, and those sentences were repeated 10 times. Durations were measured and variability of duration across repetitions of each sentence were measured to determine any significant differences between simple and complex sentence structures. *Results:* Repetition duration was shortest for simple sentences. This was found for all age groups. When comparing duration variability, significant differences between conditions were only noted in the adult group, with the complex sentence leading to more variable durations. Adults had the most stable productions when compared with the 5 year old and 8 year old groups. *Conclusion:* Adults have more stable speech patterns than children at ages 5 and 8. Duration is affected by linguistic complexity, and variability increases with increased syntactic complexity. *Relevance to the Current Work:* This study provided information that led to the current study's hypothesis that increasing syntactic complexity would have an effect on motor speech stability across an adult age range.

Barlow, S. M., Cole, K. J., & Abbs, J. H. (1983). A new head-mounted lip-jaw movement transduction system for the study of motor speech disorders. *Journal of Speech and Hearing Research, 26*, 283-288.

Objective: This article describes the head-mounted lip and jaw transduction system and its features. *Results:* The head-mounted lip and jaw transduction system is lightweight, contains a low-mass transducer unit, does not restrain the head, and the recordings have a transduction artifact of .1 mm or less. Because the most direct consequences of neuromuscular abnormalities are in muscular control, the authors consider measurements of movement more clinically useful than the acoustic measurements that result from them. *Relevance to the Current Work:* The current study uses the head-mounted lip-jaw movement transduction system to collect data on lip and jaw displacement.

Brewer, G. A., Ball, B. H., Knight, J. B., Dewitt, M. R., & Marsh, R. L. (2011). Divided attention interferes with fulfilling activity-based intentions. *Acta Psychologica, 128,* 100-105. doi:10.1016/j.actpsy.2011.05.011

Objective: The purpose of this study was to test the hypothesis that divided attention would negatively affect activity-based memory. *Method:* This study included two experiments. The first experiment had undergraduates randomly assigned to one of three tasks: a No Divided Attention (No DA) condition, which asked participants to say *now* when they finished the lexical decision task (LDT); a Divided Attention End condition, which asked participants to generate random numbers during the LDT and ended both tasks simultaneously; or a Divided Attention

Continue (DA Continue) condition, which asked participants to continue generating random numbers even after finishing the LDT. The second experiment put participants into four groups. Within the No DA and the DA Continue conditions, participants were divided by the type of intention, either activity-based or activity-based + implementation intention. *Results:* The first experiment showed that successful completion of each task at hand generally suffered when attention was being devoted to another task. The second experiment showed that negative effects of divided attention could be improved by forming an implementation intention, or by placing priority on a specific task. *Conclusion:* The results showed that activity-based memory is susceptible to distraction and that using memory-enhancing strategies can reduce the interference. *Relevance to the Current Work:* This study shows the negative effects that dual performance can have on memory as well as how these effects can be mitigated.

Brown, R. (1973*). A first language: The early stages*. Cambridge, MA: Harvard University Press.

Objective: Brown provides a description of childhood acquisition of language, as well as a system of measuring linguistic development into stages. Brown's stages are based on the relations and roles of simple sentences, modulation of meaning, and embedding sentences within one another. *Relevance to the Current Work:* Brown provides a means of measuring linguistic complexity, as well as insight into how childhood language develops. Brown's stages of language acquisition were used to create levels of linguistic complexity in the study by Maner et al. (2000).

Carnahan, H., Elliott, D., & Lee, T. D. (1986). Dual-task interference between speaking and listening and a unipedal force production task. *Neuropsychologia, 24*, 583-586. doi:10.1016/0028-3932(86)90102-8

Objective: The objective of this study was to learn how concurrent auditory and verbal tasks affect motor performance. *Method:* This study included 24 typical right-handed male adults. Participants produced forces with their left and right feet in isolation, then while sound shadowing or listening to high frequency words. *Results:* Participants performed better with their left foot than their right foot. Sound-shadowing, but not listening, disrupted the right foot performance, while neither had an effect on left foot performance. *Relevance to the Current Work:* This study shows that auditory perception of language does not negatively affect concurrent tasks, but that speech production does. Findings like these form the basis for the functional distance hypothesis.

Chang, P., & Hammond, G. R. (1987). Mutual interactions between speech and finger movements. *Journal of Motor Behavior, 19*, 265-274.

Objective: This study tested the hypothesis that proximity of neural control of different functions is what causes the interaction in concurrent tasks to decay. *Method:* Participants of this study were right-handed males. Participants repeated a syllable as they made cyclical finger movements with the left and right hands, and measurements were made of speech output and finger movements. There were three experimental conditions: maintaining constant-amplitude in both, alternating speech amplitude while maintaining constant finger movement, and alternating finger amplitude while attempting to maintain constant speech amplitude. *Results:* Speech output

and finger movement output were coupled—one system was influenced by a shift in the other's amplitude. The interactions were bidirectional and occurred in both right- and left-handed conditions. *Conclusion:* Interactions are more extensive and subtle than mere interference between the two systems. Apparently this phenomenon does not depend on the anatomical overlap of the responding neural systems. *Relevance to the Current Work:* This study found that the anatomical proximity of the neural control of different functions is too simple an explanation for the negative interference that occurs during concurrent tasks.

Cheung, H., & Kemper, S. (1992). Competing complexity metrics and adults' production of complex sentences. *Applied Psycholinguistics, 13*, 53-76. doi:10.1017/S0142716400005427

Objective: The purpose of this study was to evaluate 11 different measurements of linguistic complexity to determine which would measure complexity most effectively. The metrics included: Mean length of utterance (MLU), mean clauses per utterance (MCU), Developmental Sentence Scoring (DSS), Index of Productive Syntax (IPSyn), Developmental Level (DLevel), Directional Complexity (DComplexity), two ways of measuring Yngve depth, two variations of Frazier's node count, and Propositional Density (PDensity). *Method:* Each metric was applied to 30 language samples provided by 60-90 year old speakers, and analysis determined how well age group and individual complexity measurements were reported. Complexity of language samples was also tested by having a panel of judges listen to verbal production of a sentence in the presence of noise, assess its comprehensibility, and repeat it back verbatim. *Conclusion:* The most predictive measurements of how easily sentences are understood and recalled was the amount of embedding and type of embedding within the sentence. *Relevance to the Current Work:* This study provided insight into appropriate measurements of linguistic complexity to employ in the current study.

Crystal, D. (1987). Towards a 'bucket' theory of language disability: Taking account of interaction between linguistic levels. *Clinical Linguistics & Phonetics, 1*(1)*,* 7-22.

Objective: The purpose of this study was to examine language models in order to explore the interactions of linguistic levels and the effects that these interactions have on individuals with language impairment. The author of this study was interested in how these interactions would support certain linguistic planning models of brain function. *Method:* A sample of spontaneous speech from a child with language impairment and disfluencies was analyzed to determine which interactions were causing breakdown in speech production. *Results:* Fluency deteriorations were noted in the presence of more advanced LARSP structures. Increases in segmental phonology complexity led to decreased intelligibility of speech. Syntax and semantics influenced one another—when semantic complexity increased, syntactic complexity decreased, and vice versa. Discourse level of organization impacted every level, and was noted during complete breakdown of all areas of speech during narrative production. *Conclusion:* The author concluded that additional research into error patterns in language should be completed. He also concluded that the results did not support a notion of "hierarchy" in language processing, but instead introduced an analogy of a bucket: Each individual possesses a bucket that is filled with linguistic demands. As increasing linguistic demands are placed on an individual, the bucket can overflow and cause a performance breakdown. *Relevance to current work:* Crystal provides the 'bucket" theory of linguistic processing, which is presented in the current study as support for the limited capacity theory.

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

Objective: The purpose of this study was to test the hypothesis that manual motor activity would impact speech movements' displacement and velocity, where cognitive and linguistic demands would affect the consistency of lip movements. Another purpose was to examine how speech affected the other tasks. *Method:* This study used 29 typical young adults for participants. Each passed a hearing screening and reported no history of speech, language, or hearing disorders. Participants' lip movements were measured in isolation and concurrently with a linguistic, cognitive, and visuo-motor task. The experiment also measured the performance in the non-speech tasks in isolation and when concurrent with speech. *Results*: Linguistic challenges resulted in variability of lip displacement, and motor challenges led to more rapid speech and decreased displacement. Vocal intensity increased in each concurrent task. Performance scores decreased during the concurrent linguistic and speech tasks only. *Conclusion:* The different results as conditions were altered suggest that the levels of attention required during motor and linguistic tasks are different. Data also suggest that concurrent tasks require more effort from the speaker. Due to the linguistic performance decline, it is suggested that speech and language both influence each other. It suggests that when working with disordered speakers, it is important to consider the demands of language formulation, cognitive activity, and speech motor performance. *Relevance to the Current Work:* This study was a precursor to the current study that showed that divided attention influences performance in each task.

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,* 1234-1246. doi:10.1044/1092-4388(2003/096)

Objective: The purpose was to examine how concurrent tasks influence speech motor performance. The researchers hoped to find differences in speech movements that related to the nature of the concurrent tasks. *Method:* 10 male and 10 female young adult native English speakers who passed a hearing screening participated in the study. Each participant had to successfully complete each task in isolation prior to beginning the study. Tasks included: speech-only, speech and motor, speech and linguistic, speech and cognitive. Measurements of duration, displacement and velocity, correlation, and Spatiotemporal Index (STI), were analyzed. *Results:* Lip displacement decreased in the concurrent speech and motor task, STI increased during the concurrent speech and linguistic task, and speech rate and STI increased during the concurrent speech and cognitive task. *Conclusion:* Distractor tasks during speech have significant influence on speech production. Data suggest that speakers have the ability to shift neural resources to different aspects of communication when situational demands increase. *Relevance to the Current Work:* This is one of the initial experiments of speech performance with concurrent tasks. It is a precursor to the current study.

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,* 446-454. doi:10.1080/17549507.2010.485649

Objective: The purpose of this study was to examine dual task interference between speaking and postural stability in individuals with Parkinson's disease. *Method:* 9 individuals with Parkinson's disease, 7 age-matched controls, and 10 healthy young controls participated. Participants with Parkinson's disease were instructed to repeat an utterance and perform a rise to toes task in isolation and concurrently, in an attempt to determine the interference between speech production and postural control in individuals with this disease. Sensitive measures for both speech and posture control were obtained. *Results:* The group with Parkinson's performed more poorly than both control groups for the toe-rise in isolation, but not significantly differently in the speech-only task. In combination, the Parkinson's group had reduced diphthong extents and slopes, as well as slower and less stable toe-rises, which is evidence of dual task interference for both tasks. *Conclusion:* Speech and postural control affect each other negatively in this population and could result in risk during daily activities. *Relevance to the Current Work:* This study shows how dual task interferences are amplified in a disordered population.

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*, 1171-1182. doi:10.1044/1092-4388(2008/06-0221)

Objective: The purpose of this study was to test the functional distance hypothesis, which theorizes that two tasks controlled by proximal areas in the brain will interfere with one another more than two concurrent tasks controlled by anatomically distant areas of the brain. The researchers specifically studied whether right-hand activity would interfere with language and speech more than the left-hand, due to the proximity of the left motor strip with the speech and language areas of the brain. *Method:* The participants were native speakers of English, with no history of speech, language, or hearing disorders. Each participant was right-handed and each passed a hearing screening. Participants repeated a sentence, listed words beginning with the same letter, and performed a right or left handed motor task in isolation and concurrently. *Results:* During concurrent performance of manual tasks, there was a decrease in displacement and velocity, but an increase in sound pressure level. Spatiotemporal variability increased during the non-dominant hand motor task. Motor scores decreased significantly during a concurrent speech task. *Conclusion:* It is concluded that the functional distance hypothesis is too simple an explanation for what is occurring in the brain during concurrent tasks. *Relevance to the Current Work:* This study revealed limits of the functional distance hypothesis while providing additional evidence of the impact of concurrent linguistic and motor tasks on speech production.

Friedman, A., Polson, M. C., & Dafoe, C. G. (1988). Dividing attention between the hands and the head: Performance trade-offs between rapid finger tapping and verbal memory. *Journal of Experimental Psychology: Human Perception and Performance, 14*, 60-68. doi:10.1037/0096-1523.14.1.60

Objective: The purpose of this study was to test the multiple resources approach, which states that each hemisphere of the brain controls its own set of resources, and that it cannot share with the other hemisphere. *Method:* This study was performed with 48 typical right-handed men. Participants performed a verbal memory task while tapping an index finger concurrently.

Results: Participants remembered more on the verbal task when concurrently tapping with the left hand, than when using the right hand. If the memory task was emphasized, the participants did better on that task. When the participants were reading the words, tapping was not affected more on one hand than the other, but when the memorized words were produced, tapping decreased significantly more for the right hand than the left. *Conclusion:* The researchers speculated that the reason for the results is that the left hemisphere controls both language production and movements of the right hand. Thus they suggest that cognition and motor resources may be independent and that manipulating task priority may be important. *Relevance to the Current Work:* This study supports the idea that prioritization is important, as well as offers support for the multiple resources model and functional distance hypothesis.

Givón, T. (1991). Markedness in grammar: distributional, communicative and cognitive correlates of syntactic structure. *Studies in Language, 15*(2), 335-370. doi:10.1075/sl.15.2.05giv

Objective: Givón discussed markedness of language structures that contribute to syntactic complexity. Markedness depends on structural complexity, frequency distribution, and cognitive complexity of the syntactic figure. He also identified the context in which the syntactic figure is found as having an impact on overall syntactic complexity. Givón divided grammatical categories into discourse types, clause types, nominal modalities, and verb modalities. In each of these categories, structural complexity was addressed. Givón cited two extremes of clause complexity as conjoined forms being unmarked and less complex than an embedded syntactic form. He discussed additional structural changes that affect markedness and complexity, including tense, noun and verb phrase positioning, finiteness, and active/passive differences. *Relevance to the Current Work:* Givón's discussion of syntactic complexities provided guidance regarding how to alter syntactic complexities—with conjoined sentence structures being less complex than embedded sentence structures.

Green, J. R., Moore, C. A., & Reilly, K. J. (2002). The sequential development of jaw and lip control for speech. *Journal of Speech, Language, and Hearing Research, 45*(1), 66-79. doi:10.1044/1092-4388(2002/005)

Objective: This experiment examined jaw and lip control across age groups. The aim of this study was to gain insight into the development of adult-like speech patterns. *Method:* Participants were split into four age groups: infants (age11-13 months), toddlers (age 23 to 29 months), children (age 6-7 years), and adults (age 27-35 years). Speech samples were recorded of the participants producing a bilabial CVCV utterance: *baba*, *mama*, and/or *papa*. Movements of the upper lip, lower lip, and jaw were measured and compared between age groups and between same-age peers. *Results:* Jaw movements of infants and toddlers were more adult-like than their upper lip and lower lip movements. Upper lip and lower lip movements became more adult-like as the children matured. *Conclusion:* This study concluded that jaw movements mature more quickly than upper and lower lip movements, but that upper lip and lower lip movements reach a more adult-like movement pattern by the age of 6. The authors of this study suggested that speech sound acquisition is influenced by the maturation of lip and jaw movements. *Relevance to the Current Work:* The current study uses this study as an example of previous work done to compare motor speech movements between age groups. It shows that lip and jaw movements are nearly adult-like in their patterns by the age of 6.

Ho, A. K., Iansek, R., & Bradshaw, J. L. (2002). The effect of a concurrent task on Parkinsonian speech. *Journal of Clinical and Experimental Neuropsychology, 24*, 36-47.

Objective: This study examined Parkinsonian speech and the role that attention plays in speech control. *Method:* Fifteen patients with Parkinson's disease and 15 matched controls participated in this study. Participants performed speech tasks (one in conversation and one in numerical recitation) with and without a concurrent visuo-manual tracking task. Measurements of vocal intensity and temporal duration of speech control were collected. *Results:* Findings showed a decreased speech volume, and increased progressive volume decay in concurrent conditions. There was also increased speech initiation time and pause time, and speech rate decreased when the concurrent task began. Patients did not score lower than the controls on the visuo-motor task in any condition. *Conclusion:* The data show that patients with Parkinson's disease are at a disadvantage in automatic and non-visually controlled tasks (speech in this example). This also suggests that speech and movement control are driven by higher-order brain function that is impaired in PD. *Relevance to the Current Work:* This study relates to the current work because it showed that speech and motor movements are higher order functions and that in speech disorders where the ability of this function is weakened, the two can not be completed successfully in concurrent conditions.

Ingram, D. (1989). *First language acquisition.* Cambridge: Cambridge University Press.

Objective: This book discusses language acquisition in children. Information found in the book includes the foundations of this research, such as previous studies and explanations, as well as milestones of language development, ranging from pre-linguistic stages to the acquisition of grammatical morphemes. *Relevance to the Current Work:* The current study uses this work as an example of research that focuses solely on language acquisition rather than examining speech and language as concurrent processes. It also provides insight into the complexity of language planning and language organization, and the demands that linguistic complexity places on individuals acquiring and producing language.

Kahneman, D. (1973). *Attention and effort.* Englewood Cliffs, NJ: Prentice Hall.

Objective: This book discusses attention and the different literature and research that has been published about it. Its purpose was to form a comprehensive overview of the concept of attention by incorporating findings and ideas on the subject from various sources. It reviews research on the topic and presents interpretations of research in areas including theories of attention, the interaction between arousal and perception with attention, divided attention, and task interference. *Relevance to the Current Work:* This book provides detailed description of theories of divided attention, including the bottleneck theory, which was presented in the current study as a possible explanation of concurrent language processing and motor planning. This book also provides detailed information on divided attention and task interference.

Kemper, S., Herman, R. E., & Liu, C. (2004). Sentence production by young and older adults in controlled contexts. *Journal of Gerontology, 59B*(5), 220-224. doi:10.1093/geronb/59.5.P220

Objective: This study compared complex sentence production between older and younger adults. The purpose of this study was to assess how aging affects speech and language production. *Method:* 34 young adults and 39 older adults without hearing loss or signs of dementia participated in the task. Participants memorized sentence stems and created sentences that included that memorized stem in an attempt to study the sentence planning process. Analysis of memorization time, response latencies, and response errors were made. Researchers measured sentences based on length, propositional content, and grammatical complexity. *Results:* Young adults produced longer sentences, more propositions with increased number of words, and more complex grammatical structure, as measured by DSS. In addition to this, older adults responded more slowly, and had more frequent errors. *Conclusion:* Patterns of results suggest that older adults experience a 'ceiling' level of speech complexity and content. The authors speculate that it may be due to reduced working memory or slowed processing speed that accompany aging. *Relevance to current work:* This study provided information regarding age impact on divided attention tasks of delayed recall and linguistic planning. It also provided information regarding measurements of speech output.

Kemper, S., & Rash, S. (1988). Speech and writing across the lifespan. In M. M. Gruneberg, P. E. Morris, & R. N. Sykes (Eds.), *Practical aspects of memory: Current research and issues* (pp. 107-112). Chichester, U.K.: Wiley.

Objective: The purpose of this study was to examine how syntactic changes can minimize working memory demands. The authors used Yngve's model of sentence planning to assess how syntactic complexity changes across different age groups. *Method:* Yngve's model was applied to speech samples from adults' spontaneous productions. *Results:* Increased age correlated with a decrease in both the Yngve depth and the mean number of clauses per sentence. *Conclusions:* The results support the hypothesis that the decrease in working memory capacity that is experienced by elderly adults affects their production of syntactically complex speech. This study also suggests that syntactically complex speech requires greater processing capacities. *Relevance to Current Work:* This study provided information regarding age-group and individual differences that exist in language processing and production. Information from this study was used in Cheung and Kemper (1992), which was cited in the current study for information regarding appropriate measurements of linguistic complexity.

Kinsbourne, M., & Hicks R. E. (1978). Functional cerebral space: a model for overflow, transfer, and interference effects in human performance. A tutorial. In J Requin (Ed.), *Attention and performance VII* (pp. 345-362). Hillsdale, NJ: Erlbaum.

Objective: The purpose of this article was to explore different notions that explain the negative effects divided attention has on performance of tasks. The authors describe limited capacity theories, single-channel theories, a multi-channel hypothesis, and they propose a functional cerebral distance hypothesis. The functional distance hypothesis suggests that tasks with foci that are anatomically close will demonstrate greater interfere with one another than if the foci were distant. The authors provide experimental evidence of these interactions, including the interaction between speech and limb movements, both occurring in the left hemisphere. *Conclusions:* The authors conclude that limited capacity and single channel models are insufficient to explain the data that demonstrate dual-task interferences. They suggest that the functional cerebral distance can account for these interactions. They suggest future experimentation to determine the validity of these predictions *Relevance to Current Work:* This work is the basis for the functional distance hypothesis, which was presented in the current work as a theory of neural control during divided attention tasks.

Kleinow, J., & Smith, A. (2000). Influence of length and syntactic complexity on the speech motor stability of the fluent speech of adults who stutter. *Journal of Speech, Language, and Hearing Research, 43*(2), 548-559.

Objective: This study investigated how length and syntactic changes impact adults who stutter when compared with typical age-matched speakers. *Method:* Eight adults who stutter and eight fluent peers repeated a target phrase embedded into contexts of different syntactic complexity. Lower lip movements were measured and compared between the two groups. *Results:* Higher STIs were found in adults who stutter compared with fluent adults across all conditions. Normally fluent adults did not display any change in speech variability across conditions, but the adults who stutter did display decreased stability as syntactic complexity increased. Length of sentence alone did not affect the stability of motor speech movements in either group. *Conclusion:* This study demonstrated that linguistic complexity did have an effect on speech stability in a disordered population, but the same was not found in a typically fluent group. *Relevance to the Current Work:* The current study also examined STI changes in adults across complexity conditions. This study provided insight into how adult participants can be affected by changes in linguistic complexity.

Kleinow, J., & Smith, A. (2006). Potential interactions among linguistic, autonomic, and motor factors in speech. *Developmental Psychology, 48*, 275-287. doi:10.1002/dev.20141

Objective: The authors examined the effects of stress/arousal and linguistic changes on speech movements. The objective was to uncover potential interactions between autonomic response, linguistic complexity, and motor control. *Method:* Participants belonged to an adult group (ages 19 to 21) and a child group (ages 9 and 10). Stimuli included 4 sentences, which varied with respect to complexity and length. Simple sentences were declarative and complex sentences contained a subject relative clause. Sentences were repeated in isolation, and then repeated again following a Stroop task. The Stroop task required participants to verbalize the color with which words were written, and has been shown to cause an alteration in autonomic responses during and following task completion. Movements of the upper lip, lower lip, and jaw were measured to quantify variability across repetitions. Autonomic signals, including pulse and skin conductance, were also measured during each speaking task to determine how they interacted with linguistic complexity and motor variability. *Results:* The Stroop condition effectively raised heart rate and skin conduction level, as expected based on previous studies. While the child group showed overall greater motor speech variability than the adults, both groups demonstrated increased variability following the completion of the Stroop task. Complex sentences and longer sentences were both associated with greater variability. Sentence duration increased following the Stroop task. Increased sentence length was also associated with a greater heart rate and lower finger pulse volumes. *Conclusion:* The results supported the hypothesis that both linguistic complexity and autonomic arousal independently influence speech movements. Greater autonomic responses were not associated with the change in linguistic complexity, however. *Relevance to Current Work:* This study demonstrated the impact that changes in linguistic complexity can have on speech variability. It also confirmed the hypothesis that increased sentence length would lead to changes in speech variability. There were significant differences between motor speech patterns of children compared to adults.

Kleinow, J., Smith, A., & Ramig, L. O. (2001). Speech motor stability in IPD: Effects of rate and loudness manipulations. *Journal of Speech, Language, and Hearing Research, 44*, 1041-1051. doi:10.1044/1092-4388(2001/082)

Objective: This study examined the efficacy of the Lee Silverman Voice Treatment (LSVT) by comparing this treatment with alternative therapies. They also tested the hypothesis that individuals with Parkinson's disease have more variable motor speech patterns. *Method:* Three groups of 8 adults with Parkinson's disease participated in the study. Each of the individuals demonstrated hypokinetic dysarthria. A control group of healthy age-matched individuals was also included. Participants repeated a bilabial-loaded phrase while varying speech rate and loudness as directed. Measurements of STI, intensity, and duration were computed. *Results:* Habitual rate and loudness produced the lowest STI, while manipulations of loudness increased STI minimally, and manipulations of rate showed the greatest effect. Speaking loudly was associated with the lowest STI, while speaking slowly was associated with the highest STI for all speaking groups. *Conclusions:* Researchers noted that it may be simpler for disordered populations to maintain speech motor stability during verbal productions at a louder-than-habitual intensity. *Relevance to the Current Work:* This study demonstrated the impact that intensity and duration have on motor speech stability. The study used similar STI, intensity, and duration measurements to those in the current study.

Leclercq, M. (2002). Theoretical aspects of the main components and functions of attention. In M. Leclercq & P. Zimmermann (Eds.), *Applied neuropsychology of attention: Theory, diagnosis and rehabilitation* (pp. 3-55). New York: Psychology Press.

Objective: This chapter presents theories regarding attention and how it is managed and divided. The author describes selective attention through auditory and visual systems. Selective attention is defined as concentration on one task or idea by withdrawing from other attention demands. Theories regarding processing models and demands are presented. The author then describes divided attention and theories that have attempted to explain it, such as a single capacity theory, multiple resources theory, and various alternative explanations. *Relevance to the Current Work:* This chapter provided information regarding selective and divided attention, as well as information regarding theories of brain control in divided attention tasks, which was described in the current work.

MacPherson, M. K., & Smith, A. (2013). Influence of sentence length and syntactic complexity on the speech motor control of children who stutter. *Journal of Speech, language, and Hearing Research, 56*, 89-102. doi: 10.1044/1092-4388(2012/11-0184)

Objective: The authors wanted to determine if increased sentence length and complexity would lead to more variable speech movements in children who stutter and typically developing children. *Method:* Participants for this study included 16 children who stuttered and 16 age matched peers who did not stutter. Participants repeated four sentences of varying length and linguistic complexity, with complexity altered by the absence or presence of a subject relative clause. Each sentence was repeated following an audio presentation of the sentence until between six and 10 error-free productions were collected. Lower lip displacement and velocity were measured, as well as a comparison of upper lip and lower lip displacement referred to as lip aperture variability (LA variability). Movement duration was also measured. *Results:* Both children who stutter and the typically developing children demonstrated increased LA variability during repetitions of the longer sentence. Children who stutter had significantly higher LA variability than the typically developing children when producing syntactically simple sentences. During productions of the complex sentences, only the typically developing children had statistically higher LA variability. Movement duration was greater for long sentences than for short sentences. Duration was also greater for the more complex sentences. Within the stuttering group, no correlation was found between severity of stuttering and LA variability or duration. Length and complexity effects varied across individuals. *Conclusion:* Children who stutter had higher LA variability during speech than children who do not stutter. Children who stutter were not more affected than typically developing children when it came to length and complexity interactions, as was initially hypothesized. *Relevance to Current Work:* The current study also examined the effects of linguistic complexity on speech movement displacement, velocity, and variability. While the current study examines typically developing adults, the study by MacPherson and Smith provided important information regarding the separate influences of length and complexity on speech production.

Maner, K. J., Smith, A., & Grayson, L. (2000). Influences of utterance length and complexity on speech motor performance in children and adults. *Journal of Speech, Language, and Hearing Research, 43*, 560-573.

Objective: The purpose of this study was to establish how increasing linguistic processing demands affected speech motor output. By using concrete measurements of speech production and variability, researchers could directly observe changes in speech motor production as linguistic complexity was varied. *Method:* Participants included 8 young adults and 8 children, each with English as his or her native language, and no speech, language, or hearing impairments. Participants repeated a phrase in isolation as a baseline condition, and then embedded the phrase into sentences of varying complexity, as defined by Brown’s Linguistic Stages. Low complexity sentences were at Brown’s Stage Early IV and high complexity sentences were at Brown’s Stage Late V. STI measurements were analyzed to determine complexity’s impact on speech motor stability. *Results:* Adults generally demonstrated lower STI scores (less variability across repetitions) than children. STI was significantly increased during high complexity sentence repetition when compared to the baseline. No difference was noted between the varying sentence complexities. Length was concluded to be a confounding variable, as the baseline phrase was 6 syllables long, compared to a highly complex sentence that was 29 syllables long. *Conclusion:* These data provided novel evidence that complex language, cognitive, or motor variables have an influence on the stability of speech motor performance. Utterance length was proposed as the main cause of the variability in the speech motor performance. *Relevance to the Current Work:* This study acts as a precursor to the current study, in its attempt to examine linguistic complexity on speech motor production. Similar experimental tasks, data analysis, and hypothesis are employed in the current study. The confounding variable of utterance length provided insight into necessary changes for the selection of sentence stimuli.

Mcleod, P. (1977). A dual task response modality effect: Support for multiprocessor models of attention. *Quarterly Journal of Experimental Psychology, 29*(4), 651-667.

Objective: The objective of this article was to determine which of the dual-processing theories provides the best explanation for results of divided attention experimentation. Theories included were an independent processor theory, an executive controller theory, a single channel model, and a limited capacity model. Two experiment designs were employed to test the theories. *Experiment 1 Method:* Participants were involved in a visual input/manual output task along with a two-choice tone identification task. *Results:* Performance in the visual/manual task decreased when the auditory task was added. Both responses required more time during the concurrent task than when measured independently, showing an interaction between both independent processors and interacting processors. *Experiment 2 Method:* This design used the same visual input/manual output task as experiment 1, but included an auditory input/verbal output mental arithmetic task. *Results:* Decreased performance in the visual/manual task was noted during concurrent completion of the mental manipulation task. No significant differences were noted between varying types of arithmetic calculations. These results were similar to the first experiment. *Conclusions:* Because decreases in performance occurred during all concurrent tasks, a multiprocessor model could remain a viable explanation in the presence of overall performance decrement during simultaneous tasks. *Relevance to Current Work:* Mcleod presents information regarding a multiprocessor model of attention, which is described in the current work as a possible explanation for how attention is divided between multiple tasks.

Pashler, H. (1990). Do response modality effects support multiprocessor models of divided attention? *Journal of Experimental Psychology: Human Perception and Performance, 16*(4), 826-842. doi:10.1037//0096-1523.16.4.843

Objective: This study explored previous claims that dual-task interference decreases during concurrent tasks with varying response modalities. The author presented information on single-channel models and multiprocessor models. The author was interested in how variable stimulus order would affect responses. *Method:* 18 healthy young adults participated in this study. Participants engaged in a dual-task experiment in which they responded to stimuli with two manual responses (by pushing a button with the right or left hand). Additional participants engaged in an experiment where they responded to stimuli by one manual and one vocal response, thus creating response separation. Stimuli were presented in two ways: variable in onset time and order, or with a known and stable onset time. *Results:* In the manual/manual task (experiment 1), participants' second responses slowed as stimulus onset was altered, but there was no effect on the initial response. There were also higher error rates during variable presentation speed than during predictable presentation speed. In the manual/vocal task (experiment 2), stimulus onset variability had a significantly lower impact on task performance. *Conclusions:* The results of these two experiments demonstrated that the effect of unpredictability is much larger in the manual/manual response than the manual/vocal response, which supports a bottleneck model of dual-task interference. *Relevance to Current Work:* This study provided support for the bottleneck model, and demonstrated the impact stimulus presentation has on results.

Shiller, D. M., Gracco, V. L., & Rvachew, S. (2010). Auditory-motor learning during speech production in 9-11-year-old children. *Public Library of Science Journals, 5*(9), 1-9. doi:10.1371/journal.pone.0012975

Objective: The purpose of this study was to examine speech production changes when auditory feedback is manipulated. *Method:* Nine 11-year-old children and 13 adults participated in this study. Researchers manipulated auditory feedback during speech and analyzed participants' speech production following a period of practice under the manipulated condition. *Results:* Adults exhibited changes in both speech motor output and perceptual representation of sounds. Children also exhibited changes in speech motor output but not in their perceptual representation. *Conclusions:* Auditory feedback plays a role in motor speech production, even in children whose speech motor abilities are not yet fully developed. *Relevance to Current Work:* This work was an example of previous studies that have focused purely on motor speech production.

Smith, A., Goffman, L., Zelaznik, H. N., Ying, G., & McGillem, C. (1995). Spatiotemporal stability and patterning of speech movement sequences. *Experimental Brain Research, 104,* 493-501. doi:10.1007/BF00231983

Objective: The objective of this study was to examine stability measurements in speech production. The authors presented varying methods of measurement, including measuring timing and velocity of single movements. The authors' purpose for this study was to develop a new measurement of spatiotemporal stability while also examining the proportional scaling hypothesis, which states that speech movement sequences function by "template", meaning that stability will not be influenced by variations in speaking rate. *Method:* Participants of this study were 7 young adults without a history of speech, language, hearing, or neurological disorders. Participants were asked to repeat the bilabial-loaded phrase "buy Bobby a puppy" 20 times at a comfortable speaking rate, slowed speaking rate, and at a quickened rate. Lower lip displacement was measured by a head-mounted strain gauge system, and spatiotemporal index (STI) was measured by assessing the overall spatiotemporal stability across 15 repetitions. Timing of peak velocities was also calculated and analyzed in order to assess the proportional scaling hypothesis. *Results:* Decreasing speech rate had a significant impact on overall speech production stability, with higher STI scores in repetitions of reduced rate. No significant STI changes were noted between a comfortable and fast speaking rate. Timing of peak velocities throughout the utterance was significantly affected by variations in speaking rate. *Conclusions:* Higher STI numbers suggest that a slowed speaking rate causes a decrease in speech motor stability. Results suggest failures of the proportional scaling model because of the nonlinear changes that occurred in peak-to-peak velocities during variation of speech rate. *Relevance to Current Work:* The current work uses STI as the main method of measuring speech motor production variability. This research provided information on how to calculate this measurement as well as the benefits that this measurement metric provides. The current study also examined the effects of speech rate on STI, duration, and velocity measurements.

Strand, E. A. (1992). The integration of speech motor control and language formulation in process models of acquisition. In R. Chapman (Eds.), *Process in language acquisition and disorders* (pp. 86-107). St. Louis: Mosby Year Book.

Objective: This chapter by Edythe Strand describes the interconnectedness of speech and language formulation during childhood speech and language acquisition. She states two main purposes to the chapter, including sharing claims that demonstrate speech motor control and language formulation are interactive systems, and describing this interaction and how it affects the developmental process. She provides multiple models of language formulation and acquisition. *Conclusions:* Strand suggests that children begin with a holistic system of language and speech, but that system gradually transfers into separate systems—one that controls speech while the other controls language. She also suggested that rhythm can aid in acquisition of skilled motor movement. She provides implications for clinical practice, including the need for clinicians to understand the interconnectedness of speech and language and alter one or the other in the presence of a speech or language impairment. *Relevance to Current Work:* Strand is a leading researcher in the area of language formulation and speech motor performance. Her work demonstrates the interconnectedness of speech and language, and the current study's purpose is to add to the research in this field and determine specific ways in which these two processes interact with each other.

Szmrecsanyi, B. M. (2004). On operationalizing syntactic complexity. *Journées internationales d'Analyse statistique des Données Textuelles, 7*, 1031-1038.

Objective: This study's objective was to define syntactic complexity by comparing 3 differing ways of measuring complexity—node counts, word counts, and "Index of Syntactic Complexity". The author examined these methods' accuracy and clinical applicability. *Method:* Each of these different methods was applied to the 20 sentences of *Susanne Corpus* and the first 30 sentences of *Christine Corpus*, two corpuses of written and spoken English. *Results:* Node counts were the most accurate measurement, but word counts and "Index of Syntactic Complexity" provided nearly the same results. *Conclusions:* The author stated that since word counts are the most economical measurement to conduct, and the results showed that there was little difference in measurement accuracy, researchers can safely use word counts as a measurement of syntactic complexity. *Relevance to Current Work:* Understanding the impact of word count on syntactic complexity was crucial information during formation of target utterances. This research provided information on different methods of measuring complexity, as well as which are more applicable and accurate.

Wickens, C. D. (1976). The effects of divided attention on information processing in manual tracking. *Journal of Experimental Psychology: Human Perception and Performance, 2*(1), 1-13. doi:10.1037/0096-1523.2.1.1

Objective: The author described two common effects of dividing attention: an increase in amount of time it takes to process information, or time delay; and an increase in variability or noise in the response, also referred to as noise-added response. The author's objective of the study was to remove the ambiguity from the concept of attention by determining which divided attention effects (time delay and noise addition) were manifested during concurrent completion of tasks. *Method:* Six right-handed male students with normal hearing and vision participated in the study. Participants performed a manual tracking task concurrently with two varying tasks. The manual tracking task was chosen due to its structure, which included input of visual information, mental translation of information, and manual output. The first concurrent task was an input task of auditory signal detection and the second task was an output task, which involved applying steady physical force. *Results:* A significant decrement was noted in all areas (including time delay and noise addition) during the concurrent output task, whereas a minimal decrement was noted only in time delay during the concurrent input task. *Conclusions:* Results imply that the impact of divided attention on performance is more severe during output tasks than input tasks *Relevance to Current Work:* This article described hypotheses of neural functioning, including the single channel concept and bottleneck theories. The results of this study demonstrated that the single-channel bottleneck theory may be too simplistic an explanation 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:____________