2014-07-11

Comparing Speech Movements in Different Types of Noise

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

Master of Science

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July 2014

ABSTRACT

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This study examined the impact of several noise conditions on speech articulator movements during a sentence repetition task. Sixty participants in three age groups ranging from 20 to 70 repeated a sentence under five noise conditions. Lower lip movements during production of a target sentence were used to compute the spatiotemporal index (STI). It was hypothesized that STI would be lower (indicating greater stability) in the silent baseline condition. There were changes in speech production under several of the noise conditions. The duration for the 1-talker condition was significantly shorter when compared to the silent condition, which could be due to the impact of the 1-talker noise on the attention of the speaker. The peak velocity of a selected closing gesture increased in all of the noise conditions compared to silence. It could be speculated that the repetitive and predictable nature of the speaking task allowed participants to easily filter out the noise while automatically increasing the velocity of lip movements, and consequently, the rate of speech. The STI in the pink noise and 6-talker conditions was lower than in the silent condition, which may be interpreted to reflect a steadier manner of speech production. This could be due to the fact that in the 6-speaker noise condition, the overall effect was more similar to continuous noise, and thus potentially less distracting than hearing a single speaker talking. The count of velocity peaks was unexpectedly lower in the noise conditions compared to speech in silence, suggesting a smoother pattern of articulator movement. The repetitiveness of the task may not require a high level of self-monitoring, resulting in speech output that was more automatic in the noise conditions. With the presentation of noise during a speaking task, the intensity increased due to the Lombard effect in all of the noise conditions. People communicate in noisy environments every day, and an increased understanding of the effects of noise on speech would have value from both theoretical and clinical perspectives.

Keywords: speech motor control, lip kinematics, noise

ACKNOWLEDGEMENTS

I would like to express my utmost gratitude to my family, especially my five children Courtney, Kylie, Thomas, Todd and Trevor, my supportive husband Tracy, and unselfish parents Nelson and Lucille, for their help, support, patience, and sacrifice while I worked on this project. I also want to thank all the 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. This research project would not have been possible without the support of Dr. Christopher Dromey, who provided numerous hours of consultation, training, data collection and revisions. I would additionally like to express gratitude to Dr. Ron Channell and Dr. Shawn Nissen for their time, expertise, and support. This has been a rich and fulfilling educational experience for which I will always be grateful.

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DESCRIPTION OF CONTENT

This thesis is the result of a research project and portions of this thesis may be published as part of articles listing the thesis author as a co-author. The body of this thesis is written as a manuscript suitable for submission to a peer-reviewed journal in speech-language pathology. An annotated bibliography is presented in Appendix A and an informed consent is presented in Appendix B.

Introduction

This study examined the effects of different types of noise on speech production. Previous studies have shown that a number of outside factors (including various noise types) can affect speech perception. However, there have been fewer studies to determine the effects of outside factors on speech production. One study examined the impact of competing or distractor tasks on the motor control of speech (Dromey & Benson, 2003). These concurrent tasks test an individual's ability to successfully perform a primary task in spite of distractions. This study examined the effect of four types of noise on lip kinematic measures during sentence repetition.

Altered environmental conditions may influence individuals to change the way they produce speech by modifying its acoustic structure. An example is the Lombard effect, which results in an increase in speech intensity in the presence of environmental noise. This can lead to changes to speech timing, fundamental frequency (F_0), and/or intensity (Howell, 2008). One study of mechanisms of intensity change determined whether different cues to speak more loudly resulted in differences in lip and jaw kinematic measures (Huber & Chandrasekaran, 2006). The study revealed that different cues (e.g., reading a sentence at a participant's comfortable loudness and pitch and then at twice the comfortable loudness or pitch) had little effect unless the cues were accompanied by noise, in which case there were changes in lip and jaw movement parameters as well as in consistency. For example, in one test, participants were asked to read a sentence in the presence of multi-talker babble played at 70dBA (Huber & Chandrasekaran, 2006). Consistent with the Lombard effect, increasing the noise level led to an increase in both sentence duration and speech intensity.

Speech in noise research has investigated the impact of noise on speech processing in listeners. One such study analyzed the changes in the processing of speech and non-speech sounds in several noise conditions (Kozou et al., 2005). Specifically, Kozou and colleagues analyzed the effect on speech processing of four noise conditions—babble, industrial, traffic, and wide-band noise—compared to silence. They speculated that increased speaking intensity in noise conditions could be caused by a negative feedback mechanism for regulating voice level. Results of the study suggested that the brain in both the silent and the noise conditions processed speech and non-speech sounds differently.

Even when presented with equally complex speech and non-speech sounds, the brain will differentiate between them and process them differently. For example, constant masking sounds such as babble and industrial noise were found to have a more profound effect on speech perception than intermittent noise such as traffic sounds. However, speech processing was most impaired in traffic noise due in large part to its variability and constant fluctuations in sound intensity and frequency. It was found that exposure to the four noise types, which as the authors noted reflected everyday listening situations, does have an impact on the central auditory processing of speech and non-speech sounds, with speech being more affected than non-speech sounds (Kozou et al., 2005).

Another type of auditory distraction that has been found to have a profound effect on speech is delayed auditory feedback (DAF). DAF is a system whereby users can speak into a microphone and hear their speech played back through headphones at a delay. Research shows that speaking accompanied by a slightly delayed playback of the individual's own words leads to prolonged medial vowels (referred to in the study as *drawling)*, increased intensity, monotone pitch, slower speech, and an increase in speech errors. A clearly positive effect of DAF on speech occurred with people who stutter, where a speaker's fluency improved when speech was accompanied by a delayed playback of the individual's own speech (Howell, 2008).

Not all noise is detrimental. Stochastic resonance (SR) is a phenomenon that occurs in a nonlinear man-made or biological system, where noise below the level of the signal will cause the signal to be increased above the threshold, increasing the signal to noise ratio (Moss, Ward, & Sannita, 2004). For example, in the case of speech accompanied by soft music, the speech signal may experience a boost as a result of the music, which would be considered the noise. In this instance, the *noise* has been shown to be beneficial. But, if the level of noise increases beyond the stochastic limit, or the limit at which the noise ceases to boost the signal, it becomes masking; for example, loud music can mask a speech signal.

All of these studies have suggested that noise modulates brain activity. However, it is through brain imaging studies that researchers can monitor the effects of noise and whether it enhances or suppresses discrimination of a stimulus (Kozou et al., 2005; Schmidt et al., 2008). MRI studies have demonstrated that noise has a complex effect on neural functions underlying speech processing. Results suggest that some functions related to speech perception become redistributed from the left hemisphere to the right when listening in the presence of certain types, levels, and combinations of noise (Cunningham, Nicol, Zecker, Bradlow, & Kraus, 2001). The underlying reason appears to be that some noise types may cause fine-structured speech signals to be perceived as non-speech-like acoustic events, which normally are processed in the right hemisphere (Shtyrov, Kujala, Palva, Ilmoniemi, & Naatanen, 2000). It could be speculated, therefore, that the processing centers active in speech production may also be adversely affected in a manner similar to those used in perception. This could potentially lead to changes in the way speech is produced on the basis of the type of noise the speaker is exposed to while speaking.

Another study of the effect of noise on speech processing examined long-term noise exposure when the mechanism for hearing is intact (Kujala et al., 2004). The researchers found that the effects of noise on the cortex and behavior can be long lasting. Background noise has been found to have a more suppressive effect on the auditory processing of speech than on non-speech stimuli. As such, it could be hypothesized that the functioning of the speech module, or the part of the brain specialized in analyzing speech sounds, is more easily disturbed by noise than structures involved in non-speech auditory processing. Attention control and the ability to focus on the visual motor primary task (the participants played a computer game requiring them to track a designated target) have been found to be aberrant in noise-exposed subjects (Kujala & Brattico, 2009; Kujala et al., 2004). Noise exposure changed the hemispheric lateralization of the speech sound discrimination, decreased the processing speed of small sound contrasts, and tended to affect non-speech versus speech neural discrimination (Brattico et al., 2005).

Speaking in noise has been shown to elicit an automatic increase in vocal loudness in a speaker without any other explicit cue. This may be different than instructing a study participant to speak more loudly, suggesting that a direct request to speak loudly may cause a speaker to consciously focus on a loudness level (Huber & Chandrasekaran, 2006). Dromey & Ramig (1998) did not find a change in speaking rate when participants were asked to speak twice or four times as loudly as normal. However, when speakers increased loudness automatically to overcome environmental noise, they also tended to speak more slowly, possibly to improve intelligibility. This leads to the idea that different cues to increase loudness may lead to differences in lip and jaw kinematics. Additionally, the Huber and Chandrasekaran study found that different cues to alter speech loudness did not result in large changes to lip and jaw movement (2006). However, differences in noise cues, or the instruction an individual is given for speaking clearly in noise (e.g., speak more clearly or speak louder) have resulted in speech changes, namely increasing loudness and slowing speech rate. Not only did speakers reduce their rate of speech in noise, but speech production in noise was clearer than speech produced in quiet. Also, once speakers adjusted to louder speech levels, they tended to maintain their speech their speech movement behaviors at that speech loudness (Huber & Chandrasekaran, 2006).

The invention of speaker recognition instruments or *ID instruments* has created additional means to investigate the effect of noise on the speech production of individuals. ID instruments enable identification of individuals through the characteristics of their voice. Each individual has distinctive normal speech parameters which can be identified, recorded, and programmed into an ID instrument, with the result that the instrument can correctly identify and accept what is called an in-set (approved) speaker, and correctly identify and eliminate an out-of-set (non-approved) speaker (Ikeno, Varadarajan, Patil, & Hansen, 2006). A study was conducted in 2006 where both in-set speakers and out-of-set speakers spoke into an ID instrument against various kinds of noise. All speakers spoke identical sentences into the instrument under three noise conditions: pink noise, large crowd noise, and noise of a car travelling at high speed on a highway. The purpose of the study was to see what speech differences might occur under Lombard effect conditions (defined as altered speech produced under increased vocal effort), in this case by increasing noise levels. Previous studies had shown that the Lombard effect changes speech in several ways, including its fundamental frequency, intensity, duration, and spectral slope. The Ikeno et al. (2006) study showed several things: (a) the Lombard effect altered the speech production of tested speakers, at times making them indistinguishable to the ID instrument; (b) Lombard speech showed fundamental changes in the phoneme spectral structure of speakers; (c) programming the ID instrument to filter out the outside noise was insufficient for the ID instrument to achieve satisfactory operation; (d) the Lombard effect caused fundamental changes in speech structure not presently recognized or compensated for by the existing ID instrument. It has been shown, therefore, that the Lombard effect, whether alone or in combination with noise, degrades ID instrument speech recognition performance to a greater degree than does noise itself (Ikeno et al., 2006). This study demonstrates that the production of speech changes considerably in the presence of noise to the point that the ID instrument no longer recognizes the speaker. It can be concluded from these findings that speech production must change in other important ways, beyond just increasing in loudness. Therefore, it would be valuable to examine potential changes in speech movements under several noise conditions.

Why speech production and perception mechanisms respond as they do is not entirely known. We do know that speech processing in the brain is asymmetrical, normally with segmental speech perception and production in the left hemisphere and processing of the prosodic and emotional aspects of speech in the right hemisphere. One study of the brain to confirm lateralization of speech functions showed that when speech was heard in a quiet atmosphere, it was processed in the auditory cortex of the left hemisphere (Shtyrov et al., 1998). On the other hand, when speech was heard with background noise greater than a specific intensity level, activity diminished in the left hemisphere but increased in the right. This was also demonstrated where sensory speech processing was redistributed between the hemispheres in real-life listening situations involving background noise (Shtyrov et al., 1998). It could be speculated that this type of hemispheric reorganization could influence speech motor performance, not just perceptual processing.

Attention is the ability to focus the brain's processing capabilities on a particular phenomenon, while ignoring others. At the core of the notion of attention is concentration

(McDowd, 2007). How well an individual is able to focus on key information and ignore irrelevant information, for example, how one chooses to attend to a conversational partner and *tune out* environmental noise, is indicative of that individual's control of attention. It has been suggested that there is a pool of attention capacity available for use on multiple simple tasks, or prioritized complex tasks (Kahneman, 1973). If one is multitasking and the tasks become complex, performance suffers or tasks will have to be prioritized and performed sequentially, depending on their importance. Several different types of attention have been defined including: selective attention (attending to a chosen item while ignoring others); divided attention (processing more than one source of information or multiple tasks at the same time); attention switching (alternating attention from one task to another); and sustained attention (maintaining attention over a longer period of time; Kahneman, 1973). Additionally, unlike some processes in the brain that are localized, attention is thought to rely on multiple areas of the brain, which may explain why patients with very different types and sites of brain injury struggle with attention (Mukherjee, Levin, & Heller, 2006). Two prominent models of attention are Posner's attentional network and Mesulam's attentional matrix (Daffner, Ahern, Weintraub, & Mesulam, 1990; Mesulam, 2000; Petersen & Posner, 2012; Posner & Petersen, 1990). Posner and his colleagues identified the key components of attention as alerting, orienting, and executive control. Their theory maintains that while these are separate functions, there is interaction among them. Because these three functions are attributed to different regions in the brain, the type of damage an individual has can help predict the source and type of attention difficulty and this may help direct treatment (Petersen & Posner, 2012; Posner & Petersen, 1990). Mesulam's matrix is a combination of (a) modality-specific processing, such as is carried out by primary sensory areas, (b) bottom-up attentional modulation from the ascending reticular activating system, and (c) top-down attentional modulation from prefrontal, parietal, and limbic areas of the brain (McDowd, 2007; Mesulam, 2000). These models illustrate the complex and multifaceted nature of attention in typical adults. A critical aspect of focusing attention is to selectively ignore, or filter out, irrelevant noise. Studies show that some types of noise are theoretically simpler to filter out than others. Those that are harder to ignore (e.g., those that affected the accuracy of the ID instrument) might have a more significant impact on how we speak.

Attention-deficit disorder (ADD) and attention-deficit/hyperactivity disorder (ADHD) are conditions typically diagnosed in childhood that can linger into adulthood and are characterized by difficulty maintaining attention. A study of adults with ADD/ADHD examined the premise that the attention difficulties related to these disorders involved an impairment of intentional inhibitory control (Roberts, Fillmore, & Milich, 2011). Attention of these individuals would suffer because of an inability to filter out and deny attention to irrelevant information, including environmental noise, and extraneous information. Inhibitory control has been defined as three interconnected processes, including inhibiting prepotent responses, inhibiting ongoing responses, and interference control (Barkley, 1997). These individuals have increased difficulty keeping attention on relevant stimuli and away from irrelevant stimuli, can be easily distractible, and often have difficulty with working memory which optimally requires functional attention. This lack of inhibitory control in adults with ADD/ADHD theoretically exacerbates the negative impact of noise on speech production already demonstrated in adults with normal inhibitory control.

Dromey and Benson (2003) reported a study in which participants were required to produce speech simultaneously with three different types of distractor tasks: motor (assembling washers, nuts and bolts), linguistic (generating verbs from nouns), and cognitive (performing mental arithmetic). Because the distractor tasks were of different types, it was speculated that different neural resources might be affected. Lip and jaw movement data collected during the experiment revealed decreases in displacement and velocity during the motor task. The linguistic and cognitive tasks were accompanied by increased upper and lower lip displacements. This shows that the nature of the distractor task can influence labial kinetic measures in different ways, and suggests that the neural resources allocated to different aspects of communication may shift depending on situational demands. More errors were noted when the speech task was accompanied by the linguistic task, which suggests that the same neural resources were involved in speech movement and language formation. The motor distractor task did not significantly affect lip coordination measures, which suggests that different neural resources were involved and were not competitive. Lieberman (2001) demonstrated how speech and language are integrated, noting that the neural bases of human language are intertwined with other aspects of cognition, motor control, and emotion (Lieberman, 2001). The way speech movements are executed may be compromised when language processing demands increase. Maner, Smith, and Grayson (2000) showed that increased utterance length and complexity resulted in greater variability in a phrase repeated by speakers. This shows that non-motor processes such as language and cognition can influence speech kinematics.

Cognitive psychology has developed two theories about how the brain may address simultaneous tasks. The first theory is that there is a pool of cognitive resources that can be divided or shared among competing tasks; the second theory is that the brain processes tasks serially, that is, addresses tasks one at a time (Kahneman, 1973; Wickens, 1984). A subsequent refinement suggests that the brain may have multiple processors that can be dedicated to multiple tasks (McLeod, 1977).

Previous studies have analyzed the effects of distractor tasks on speech motor control. It has also been shown that altered environmental conditions may influence an individual to change the way they produce speech by modifying its acoustic structure, as can occur with the Lombard effect. Unlike previous studies, the present study explored the effect of different types of noise on motor speech performance. Specifically, this study was designed to reveal whether listening to one, two, or six speakers while repeating a sentence would have a different effect from pink noise because of the potential for linguistic content to engage the speaker's attention more than unchanging noise. Furthermore, while previous work has examined how the brain prioritizes and filters noise during auditory perception, this study considers a speaker's capacity to overcome the potentially distracting effects of noise while speaking.

Method

Participants

Thirty male and 30 female native English speakers participated in this study. There were 10 male and 10 female native English speakers in each of three age groups: 20-30, 40-50, and 60-70. 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 at the vermillion border. A strain gauge 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 of the data for each participant were collected within a one-hour session. This experiment was part of a larger study that involved other speaking tasks. Each participant was asked to repeat the sentence, *In Panama most people prefer to travel by bus, bike, or boat,* 15 times under one of five randomly-sequenced listening conditions. Audio stimuli were presented via Sony MDR-EX10LP 3.5mm earbud headphones. In order to establish the intensity level of the stimuli, the pink noise stimulus was matched to masking noise from an audiometer at 65 dB HL. Using Adobe Audition, all of the stimuli were equalized in amplitude to the pink noise. The sentence appeared on a 60.9 centimeter monitor with a blank slide in between repetitions. The listening conditions presented were: the speech of one person reading aloud a novel, two simultaneous readers, six simultaneous readers, pink noise, and a silent baseline condition.

Participants were instructed to repeat the sentence 15 times at a comfortable speaking rate and loudness. The order of listening conditions was randomized in order to minimize sequencing effects. The tasks were explained and practiced five times before data were collected in order to minimize learning effects.

Data Measurement

The digital recordings of the lower lip movement (including the jaw's contribution, rather than being decoupled from it) were analyzed with custom MATLAB (MathWorks, 2012) routines. Measurements included utterance duration, sound pressure level (SPL), lip displacement and velocity, and further measures of lip coordination and movement stability.

Duration. Target phrase duration was measured in milliseconds each time the sentence, *In Panama most people prefer to travel by bus, bike, or boat,* was produced. The target phrase for kinematic analysis was segmented from the lower lip record, starting at the downward velocity peak during the first opening movement from /p to /æ/ in *Panama* and ended at the upward velocity peak during the closing movement from /æ/ to /v/ in *travel*. The duration was measured to assess possible changes in speaking rate as a function of listening condition. Segmentation points are shown in the lower panel of Figure 1.

Displacement and velocity. Displacement of the lower lip was measured for the closing gesture from the /æ/ to the /n/ of the word *Panama* from each production as shown in the top panel of Figure 1. The peak closing velocity was computed from the same gesture. These measurements were made in order to better understand how the noise condition might influence the magnitude and speed of the articulatory movements.

Upper lip/lower lip correlation. The upper and lower lip displacement records from the same closing gesture in the first syllable of *Panama* were used to compute the correlation between the upper lip and lower lip displacements. This quantified the extent to which the upper and lower lips moved in opposite directions; a correlation of -1 would indicate that the upper and lower lips moved in exact opposition to each other. This measure was used to examine whether listening conditions would influence the coordination of speech movements.

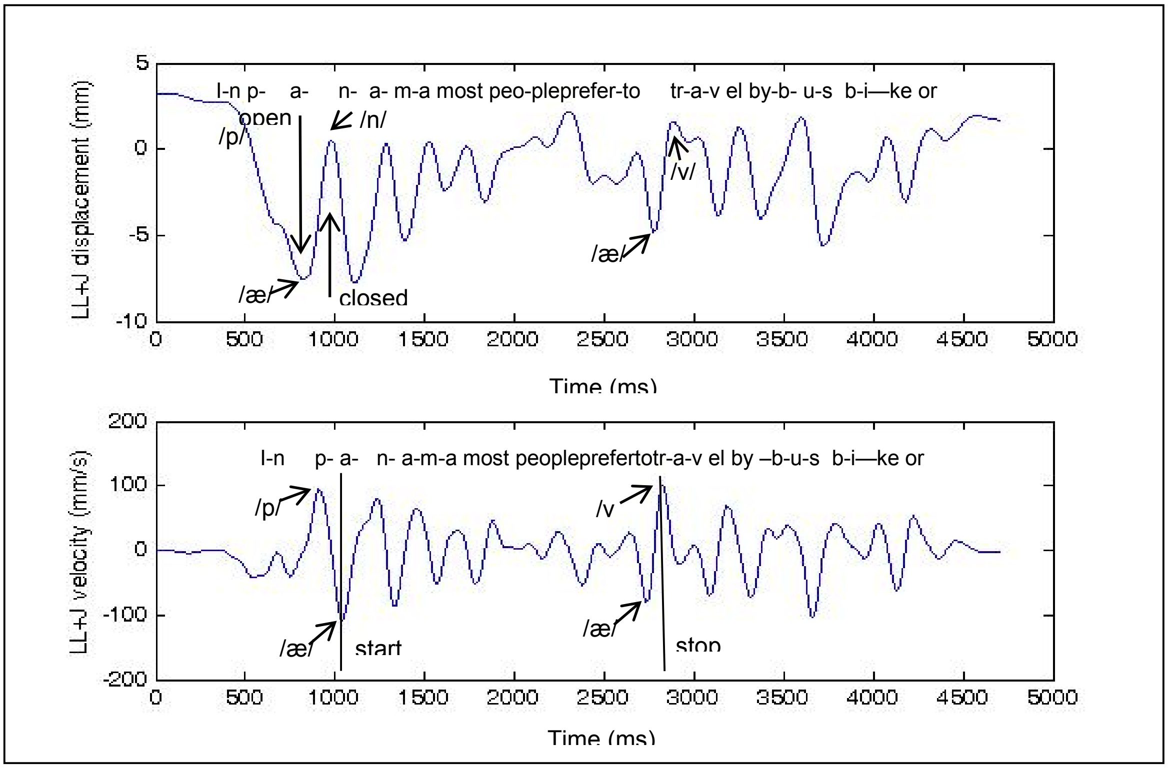

Figure 1. Displacement and velocity waveforms from one repetition of the target phrase, showing segmentation points.

Spatiotemporal Index (STI). Ten segmented displacement waveforms of the target phrase 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 in previous reports (Kleinow, Smith, & Ramig, 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, Goffman, Zelaznik, Ying, & McGillem, 1995). This allowed the STI to measure consistency of speech articulation over multiple repetitions, where a smaller number reflects lower variability.

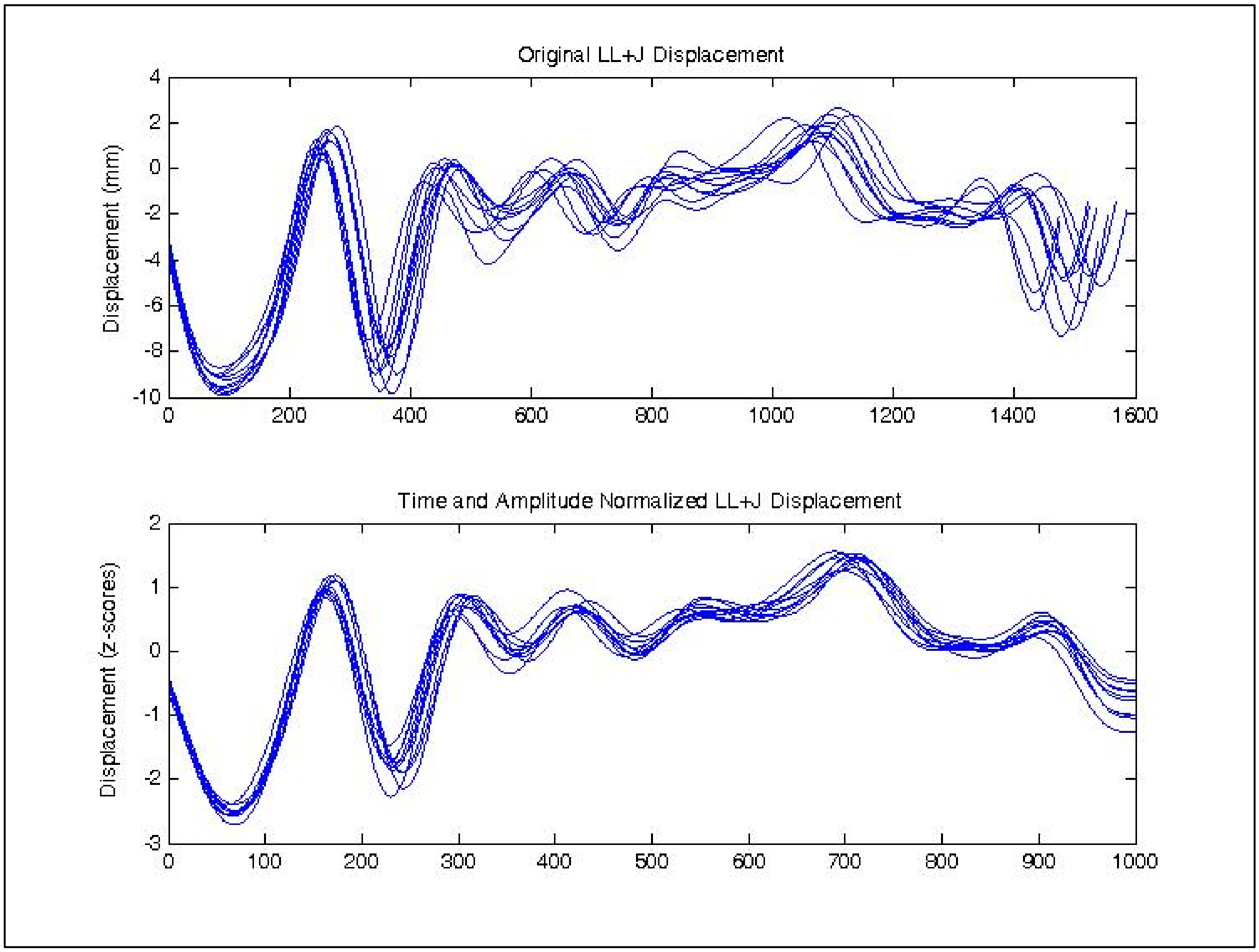

Figure 2. Ten repetitions of the original (upper panel) and time/amplitude normalized (lower panel) LL displacement records used to compute the STI.

Velocity peaks. After the velocity record of the target phrase 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 (Adams, Weismer, & Kent, 1993), and it was hypothesized that this measurement would be influenced by changes in listening condition.

Sound Pressure Level (SPL). The mean SPL for the target phrase was calculated. This measurement was made in order to learn whether listening condition 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 listening conditions. The ANOVA included the five listening conditions, with contrasts comparing each of the four noise conditions to the silent-baseline condition. Significant within-subjects effects for listening condition or between-subjects effects for age were examined with concurrent contrasts or a Tukey post hoc test, respectively. Effect size was computed as partial eta squared (η_p^2).

Results

ANOVA testing revealed a number of significant changes in speech performance across the noise conditions, as well as several between subjects effects. Descriptive statistics for the dependent measures are presented in Table 1. Significant differences across conditions or between speaker groups are reported below. In cases where the Mauchly test revealed violations of the assumption of sphericity, Huynh-Feldt corrections were applied, resulting in non-integer degrees of freedom.

Duration

There was a significant effect of noise condition on duration. $F(3.345, 180.648) = 2.650$, $p = .044$, $\eta_p^2 = .047$. The duration in the 1-talker condition was significantly shorter than in the silent condition, $F(1,54) = 6.571$, $p = .013$, $\eta_p^2 = .108$. No other contrasts were significant. There were no differences in duration by age group or gender.

Table 1

Descriptive Statistics for the Kinematic and Intensity Measures by Gender for Each Noise Condition

Condition		Silent		Pink		1- Talker		2-Talker		6-Talker	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Duration (ms)	Female	1874.18	183.99	1851.12	217.62	1831.93	200.00	1839.87	195.52	1856.98	217.25
	Male	1874.39	199.70	1843.25	203.37	1826.79	199.85	1838.46	214.34	1850.78	227.69
Displacement (mm)	Female	10.18	2.79	10.42	3.34	10.31	3.20	10.08	3.27	10.26	3.38
	Male	9.95	2.40	10.34	2.79	10.29	2.88	10.26	2.68	10.47	2.90
Velocity (mm/s)	Female	111.05	32.99	119.72	33.68	120.08	33.41	118.69	32.25	118.68	33.42
	Male	130.14	32.61	139.50	42.26	143.79	42.81	141.49	39.90	143.93	42.06
UL/LL Corr.	Female	-.74	.33	-.70	.38	-.74	.35	-.73	.30	-.75	.32
	Male	-.84	.17	-.86	.13	-.86	.12	-.86	.17	-.86	.17
LL STI	Female	13.87	3.89	12.89	3.07	13.89	4.06	13.67	3.94	13.65	4.15
	Male	16.54	4.07	14.43	4.61	15.29	4.87	15.05	4.00	14.26	4.51
Count of Vel. Pks.	Female	9.63	0.82	9.40	0.67	9.33	0.70	9.36	0.74	9.40	0.70
	Male	9.52	1.02	9.26	1.05	9.21	1.09	9.34	1.25	9.28	1.08
Intensity dB SPL at 100 cm	Female	56.68	4.15	59.99	5.44	58.89	4.89	59.80	5.71	60.47	4.90
	Male	56.45	3.63	59.42	4.14	58.31	3.78	59.67	4.02	60.34	4.08

Note. Duration= segment duration; UL= upper lip; LL= lower lip (not decoupled from jaw*);* STI= spatiotemporal index; Vel. Pks.= velocity peaks

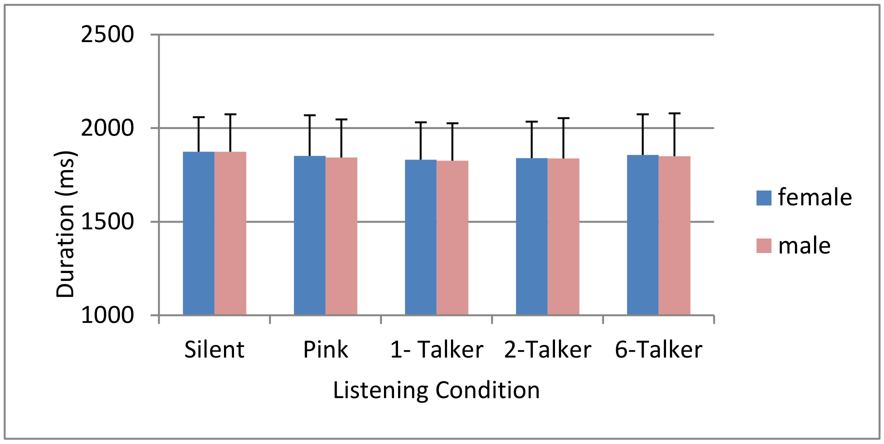

Figure 3. Means and standard deviations of the target phrase duration across the noise conditions for female and male speakers.

Displacement

There were no differences in displacement across the noise conditions. There were no between subject differences in displacement for either age group or gender.

Velocity

The velocity of the closing movement differed significantly across the noise conditions, $F(3.197,211.506) = 13.677$, $p < .001$, $\eta_p^2 = .202$. Contrasts revealed that the velocity was higher in all noise condition compared to silence. η_p^2 ranged from .281 to .406, with $p < .001$ in each case. Men had significantly higher velocities than women across all noise conditions, $F(1,54) = 5.564$, $p = .022$, $\eta_p^2 = .093$.

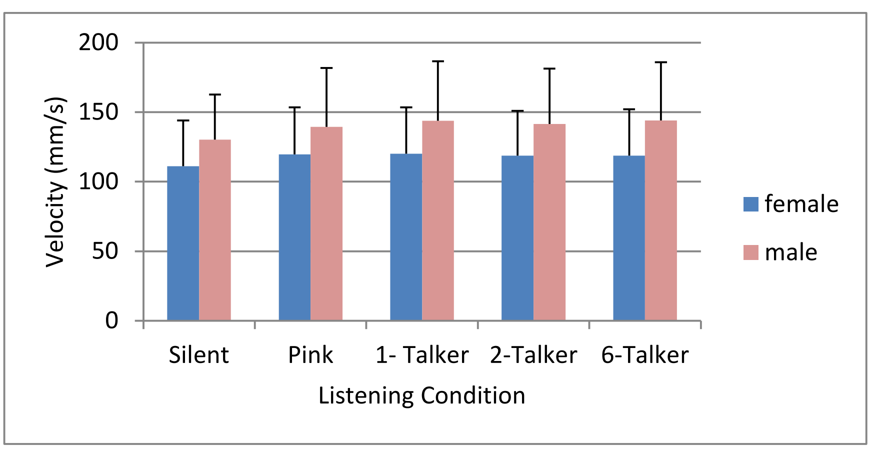

Figure 4. Means and standard deviations of the peak lower lip closing velocity across the noise conditions for female and male speakers.

Upper Lip/Lower Lip Correlation

The correlation between the upper and lower lips during the closing gesture did not change across the noise conditions. Men had a more strongly negative correlation than women, $F(1,54) = 4.197$, $p = .045$, $\eta_p^2 = .072$.

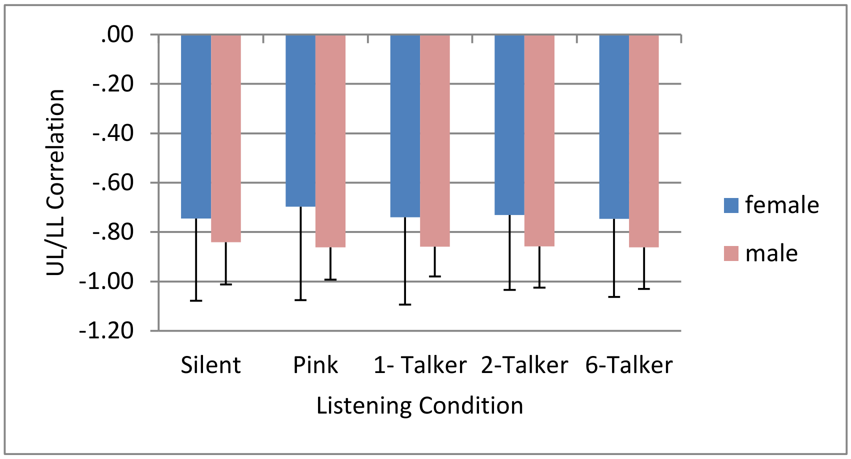

Figure 5. Means and standard deviations of the upper lip/lower lip correlation across the noise conditions for female and male speakers.

Lower Lip Spatiotemporal Index (STI)

The lower lip STI changed significantly across the noise conditions, $F(4,216) = 2.813$, $p = .026$, $\eta_p^2 = .050$. The STI was lower for the pink noise condition, $F(1,54) = 9.245$, $p = .004$, $\eta_p^2 = .146$, and for the 6-talker condition, $F(1,54) = 6.961$, $p = .011$, $\eta_p^2 = .114$, than in the silent condition. Lower lip STI was not significantly different between age groups or genders.

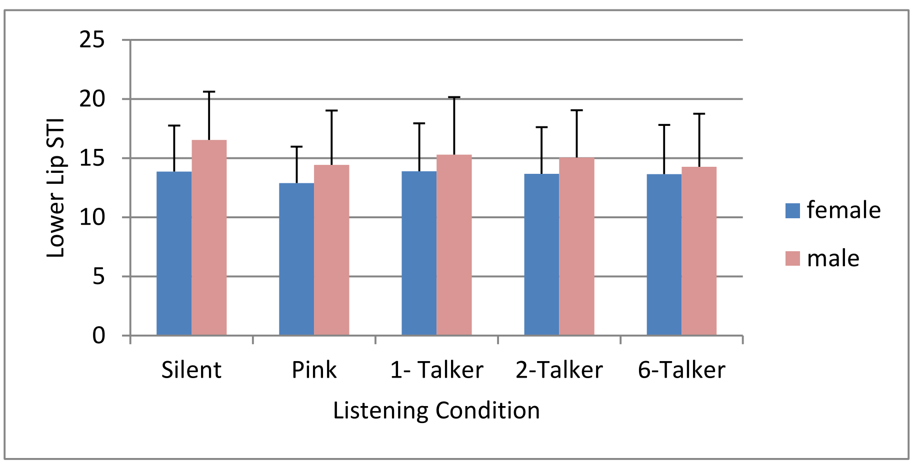

Figure 6. Means and standard deviations of the lower lip STI across the noise conditions for female and male speakers.

Count of Velocity Peaks

There was a significant difference in the count of velocity peaks across the noise conditions, $F(3.855,204.318) = 4.703$, $p = .001$, $\eta_p^2 = .082$. All noise conditions resulted in a lower number of peaks than in the silent condition. η_p^2 ranged from .004 to .071, and p ranged from .007 to .012. There were no age and gender effects for this measure.

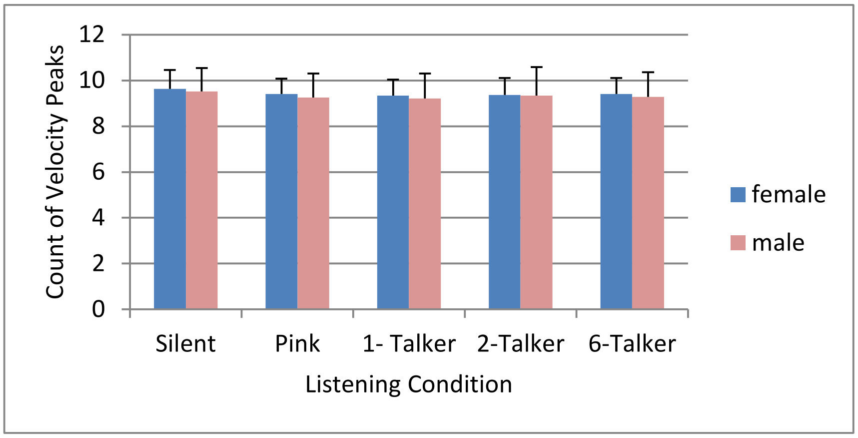

Figure 7. Means and standard deviations of the count of velocity peaks across the noise conditions for female and male speakers.

Intensity

Intensity changed significantly across the noise conditions, $F(3.001,156.061) = 85.591$, $p < .001$, $\eta_p^2 = .622$. All noise conditions resulted in a higher intensity than the silent condition, with η_p^2 ranging from .626 to .857, and $p < .001$ for all contrasts. There were no age or gender effects for intensity.

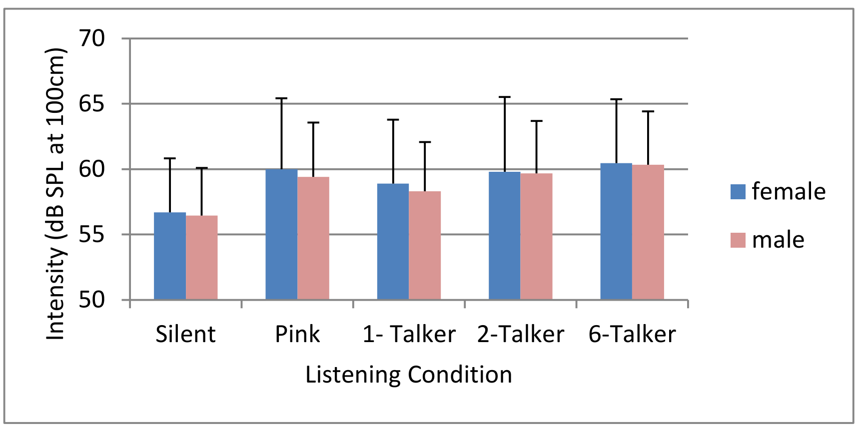

Figure 8. Means and standard deviations of the intensity of the target phrase across the noise conditions for female and male speakers.

Discussion

The purpose of the present study was to determine whether listening to noise during a sentence repetition task would influence measures of lip movement. While the data did not provide unequivocal support for the hypothesis that the type of noise would result in specific changes to speech, there were nevertheless changes in speech production under several of the noise conditions.

Duration

The duration for the 1-talker condition was significantly shorter when compared to the silent condition. It could be speculated that this was due to the impact of the 1-talker noise on the attention of the speaker. The distraction may have caused the participants to become more automated in their sentence repetitions as a compensatory response to the distraction of the noise. It is possible that the 2-talker, 6-talker, and pink noise were filtered differently by the brain, potentially even in a similar manner to non-speech sounds, thereby having less impact on speech. Previous work has shown that intermittent sounds have a more profound impact than continuous sounds on speech processing (Kozou et al., 2005). The 1-talker noise had a more intermittent quality than the 2-talker, 6-talker or pink noise. Thus the more intermittent nature of the 1-talker sound track may have proved to be more distracting, yielding speech production that was shorter in duration, less relaxed, and more deliberate. There were no other significant contrasts between noise conditions and no age and gender effects.

Displacement

There were no significant differences in lower lip displacement across any of the noise conditions, and there were no gender or age effects. Previous work has shown that volitional increases in SPL are usually associated with larger lip displacement, and that the Lombard effect can also lead to larger articulatory movements as speech becomes louder involuntarily (Dromey & Ramig, 1998). While the present finding of unchanged lip displacement with increased SPL was not anticipated, it is not without precedent. Previous studies of divided attention have also reported higher SPL without accompanying increases in articulator displacement (Dromey & Benson, 2003; Dromey & Shim, 2008).

Velocity

The peak velocity of the closing gesture increased in all of the noise conditions compared to silence. This result was not expected because displacement and velocity variables often change in the same direction, and the displacement did not change. It could be speculated that the repetitive and predictable nature of the speaking task allowed participants to easily filter out the noise while automatically increasing the velocity of lip movements, and consequently increasing the rate of speech. The faster rate of speech (yielding shorter duration) may have led to the increased velocity to allow speakers to complete the sentence more rapidly. The peak velocity of the closing gesture for men was higher than for women across the noise conditions, although it is unclear why this would be, since the displacement did not differ significantly between men and women.

Upper Lip/Lower Lip Correlation

The correlation between the upper and lower lip during the closing gesture did not change across the noise conditions. Men demonstrated a stronger negative correlation than women. This finding may be linked to the men's higher peak velocity values, suggesting a more rapid and possibly more coordinated bilabial closure action.

Lower Lip Spatiotemporal Index (STI)

The lower lip STI changed significantly across the noise conditions. The STI in the pink noise and 6-talker conditions was lower than in the silent condition. Lower STI values are typically found with a lower count of velocity peaks, both of which may be interpreted to reflect a steadier manner of speech production. It could be speculated that in the 6-speaker noise condition, the overall effect was more similar to continuous noise and thus potentially less distracting that hearing a single speaker talking. In other words, the 6-speaker distraction may have been processed by the brain as noise rather than as speech (Kozou et al., 2005). With the 1-talker and 2-talker noise conditions, individual words and phrases can be processed by the listener and may consequently be processed by the brain in the left hemisphere as speech, as opposed to non-speech noise, which has been associated with increased right hemisphere activation (Shtyrov et al., 1998).

Count of Velocity Peaks

The count of velocity peaks was unexpectedly lower in the noise conditions compared to speech in silence, suggesting a smoother pattern of articulator movement. It may be that the repetitive nature of the task did not require a high level of self-monitoring and that speech output was more automatic in the noise conditions. One study demonstrated a higher count of velocity peaks for slower more self-conscious speech (Adams, Weismer, & Kent, 1993). The authors suggested that faster speech was consistent with an open-loop motor control model, while slower speech may rely on closed-loop motor control, where speakers are reliant on ongoing feedback during slow speech. In the present study, the noise conditions resulted in faster productions (shorter utterance duration, higher peak velocities for the closing gesture), which are consistent with an open-loop motor control strategy. This suggests that noise exposure during speech may lead to more automatic and open-loop motor control strategies, while the silent condition allows slower and more deliberate, self-conscious speech, which is more variable in its movements because the results are audible to the speaker.

Intensity

It was anticipated that with the presentation of noise during a speaking task, the intensity would increase due to the Lombard effect, and this was indeed the case for all noise conditions. Intensity increased even though participants were instructed to speak at a comfortable loudness level and to be as consistent as possible. In other words, the Lombard effect was found to be an automatic adjustment on the part of the speakers, who likely were not aware that their speech was louder. These findings are similar to those from previous studies, where the presentation of noise during speech resulted in an involuntary SPL increase (Howell, 2008; Huber & Chandrasekaran, 2006).

Limitations of the Present Study

The same sentence was repeated 15 times for each condition because this allowed the computation of measures like the STI, which rely on repetition to quantify speech movement variability. As in previous studies, this allowed a high degree of experimental control, because the same dependent variables could be compared across conditions (Dromey & Benson, 2003; Dromey & Shim, 2008; Huber & Chandrasekaran, 2006). However, the repetitive nature of the task made it highly unnatural and thus not representative of everyday speaking situations where individuals express themselves in the presences of noise. The use of natural speech or speech generated in real life conditions would allow greater ecological validity, but would necessarily result in the loss of experimental control. More naturalistic studies of speech in noise would require different types of analysis that are not reliant on the use of the same words or sentences across conditions.

Directions for Future Research

Continued study of the impact of noise on speech in both typical and disordered populations, relying on more naturalistic speech tasks, would be useful in identifying more effective and targeted treatments. While the present results suggest that typical individuals are only minimally disturbed by auditory distractions in a controlled environment, it would be worthwhile repeating a similar study with disordered speakers to determine if they are similarly robust to the presence of distracting noise. People communicate in noisy environments every day, and an increase in our understanding of the effects of noise on speech would have value from both theoretical and clinical perspectives.

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Appendix A: Annotated Bibliography

Adams, S. G., & Weismer, G. (1993). Speaking rate and speech movement velocity profiles. *Journal of Speech & Hearing Research, 36*(1), 41. doi:10.1044/jshr.3601.41

Objective: The purpose of this study was to determine the effects of speaking rate on the movements of the lower lip and tongue by creating a velocity profile. This velocity profile would be indicative of motor speech processes that may be at play with reduced or increased rates of speech. *Method*: Five young adults used a magnitude production task to generate five speaking rates ranging from very fast to very slow. The lower lip and tongue tip movements were recorded during the production of stop consonants using an x-ray microbean system. *Results*: Changes in speaking rate were associated with changes in the topography of the speech movement velocity-time function. During fast speaking rates the velocity profile was symmetrical with a single-peaked function. For the slow speaking rates the velocity profile was asymmetrical with a multi-peaked function. *Conclusions*: The variation in the velocity profile was interpreted by the authors as support for the hypothesis that alterations in speaking rate are linked to changes in motor control strategies. Fast speaking rates appear to involve unitary movements that may be predominantly programmed in contrast to slower speeking rates which consist of multiple submovements that are possibly influenced by feedback mechanisms. *Relevance to the current work*: The current work makes use of a count of velocity peaks as a measure of potential speech motor control strategies in the presence of noise.

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin, 121*(1), 65-94. doi: 10.1037/0033-2909.121.1.65

Objective: This study identifies two factors of attention--automatic inhibition and intentional inhibition—in adults diagnosed with Attention-Deficit/Hyperactivity Disorder (ADHD), and compares them with a group of typical adults. *Method*: The researchers tested 30 adults with ADHD between the ages of 19 and 30 and compared them with 27 typical adults of the same age. Only participants who were currently taking medication for their ADHD were invited to participate. The participant's inhibitory control was examined using a saccadic interference task and a delayed ocular inhibitory task. They also completed the 30-question Barret Impulsiveness Scale. *Results*: The ADHD group produced significantly more saccades than the control group. The delayed ocular response tasks indicated that the ADHD group showed greater impairment on the task than on the saccadic interference task. *Conclusions*: The saccadic interference tasks measured automatic inhibitory control by measuring the ability to filter irrelevant information. The delayed ocular inhibitory task measured the ability to inhibit a saccade toward a stimulus presented in the periphery. The subjects with ADHD demonstrated an impairment of intentional inhibitory control with more than twice the number of premature saccades than the control group. This is comparable to persons under the influence of alcohol or with schizophrenia.

Relevance to the current work: Persons with an impaired ability to inhibit behaviors that lead to impaired attention may be more affected by noise disruptions than typical individuals.

Brattico, E., Kujala, T., Tervaniemi, M., Alku, P., Ambrosi, L., & Monitillo, V. (2005). Long-term exposure to occupational noise alters the cortical organization of sound processing. *Clinical Neurophysiology*, 116(1), 190-203. doi: 10.1016/j.clinph.2004.07.030

Objective: The purpose of this study was to determine whether longterm exposure to noise causes changes in the hemispheric lateralization of speech processing. It is known that noise causes lateralization of speech processing from the left to the right hemisphere. This study sought to determine whether these changes would be found in neural processing in a silent condition with individuals exposed to longterm noise, and whether the lateralization occurred with only speech or for other nonspeech sounds as well. *Method*: The authors study ten healthy noise-exposed workers and ten control participants. Brain responses were recorded with a 32-channel electroencephalogram in two conditions: standard and deviant speech sounds and other nonspeech sounds. Novel sounds were presented at random in both conditions. *Results*: The deviant sound elicited a mismatch negativity (MMN) in the control subjects that was larger in nonspeech sounds than in speech sounds. There was no difference in the noise-exposed participants. The MMN to speech sounds was lateralized to the right hemisphere in noise-exposed subjects, while it was left-hemisphere predominant in the control subjects. No group differences were found for nonspeech sounds. The deviant sounds that were closer in formant space to the standards elicited a longer MMN latency in both speech and nonspeech conditions for the noise-exposed subjects than for the control subjects. No group differences in cortical responses were found for novel sounds. *Conclusions*: Longterm exposure to noise alters the strength and hemispheric organization of speech sound discrimination. Noise-exposed subjects demonstrated a decrease in speed of the sound-changing process. *Relevance to the current work*: This work contributes to a foundation demonstrating neurological changes in speech processing that occur with noise.

Cunningham, J., Nicol, T., Zecker, S. G., Bradlow, A., & Kraus, N. (2001). Neurobiologic responses to speech in noise in children with learning problems: Deficits and strategies for improvement. *Clinical Neurophysiology,* 112, 758-767. doi: S1388-2457(01)00465

Objective: This study examined the speech sound perception deficits in background noise experienced by children with learning problems. The authors examined potential relationships between these deficits and abnormal neurophysiologic representation of speech features in noise reflected at brain stem and cortical levels. The authors also examined if these deficits could be mediated in an impaired system by acoustic cue enhancements. *Methods:* Behavioral speech perception measures in the form of just noticeable difference scores, auditory brainstem responses, frequency following responses and cortical-evoked potentials were obtained from two groups of children. One group of children had learning problems and the other group consisted of typical children. *Result:* Abnormalities were found in the fundamental sensory representation of sound at the brainstem and cortical levels in children with learning problems when speech sounds were presented in noise. During tasks in the noise condition, the children with learning problems had neurophysiologic responses that displayed a different spectral pattern and lacked precision in the neural representation of key stimuli. These abnormalities were not found in the quiet condition. *Conclusion:* The study furthers our understanding of the biological processes and the underlying perception deficits, which may lead to improvements in creating effective intervention strategies. *Relevance to current work:* This study examines the effect of noise on speech tasks for a specific population.

Daffner, K. R., Ahern, G. L., Weintraub, S., & Mesulam, M. M. (1990). Dissociated neglect behavior following sequential strokes in the right hemisphere. *Annals of Neurology*, 28(1), 97-101. doi: 10.1002/ana.410280119

Objective: This article detailed the case study of a middle-aged woman who suffered two focal right hemisphere cerebrovascular accidents (CVA) resulting in damage to anatomical structures proposed to be part of the cerebral network for the spatial distribution of attention. The first CVA was located in the right frontal lobe resulting in left hemispatial neglect. The patient then suffered a second CVA twenty days later in the parietal lobe that caused impaired perceptual-sensory aspects of neglect. This case contributed to evidence supporting the existence of a distributed anatomic-functional network that comprises attention. *Relevance to the current work*: This work identifies anatomical regions which contribute to the functional skill known as attention. The current work addresses the use of attention to complete a speaking task in noise for typical individuals to help lay a foundation for how attention may be compromised by noise in a disordered population.

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: This study evaluated the influence of three different types of concurrent tasks on motor speech performance. The purpose was to identify if there were potential differences in speech movements that could be linked to a specific secondary task. *Method*: The researchers tested 20 young adults who repeated sentences with and without distractor activities. The distractor activities included a motor task (putting washers, nuts, and bolts together), a linguistic task (creating verbs from nouns), and a cognitive task (mental arithmetic). *Results*: Lip movement data collected during the tasks revealed a decrease in displacement and velocity during the motor task. The linguistic and cognitive tasks resulted in increased spatiotemporal variability and increases in strength of the negative correlations between upper and lower lip displacement. *Conclusion*: The findings demonstrated that distractor tasks during speech can have a significant effect on labial kinematic measures. This indicates that during human communication, resource allocation may be impacted by dual tasking and situational demands. *Relevance to Current Work*: The current work aims to test the impact of noise on speech motor control.

Dromey, C., & Ramig, L. O. (1998). Intentional changes in sound pressure level and rate: Their impact on measures of respiration, phonation, and articulation. *Journal of Speech, Language, and Hearing Research*, *41*, 1003-1018. doi:10.1044/jslhr.4105.1003

Objective: This study attempted to compare the effects of changing sound pressure level (SPL) and rate on respiratory, phonatory, and articulatory behavior during sentence production. *Method*: Ten subjects—5 men and 5 women—repeated the sentence, "I sell a sapapple again," under 5 SPL and 5 rate conditions. From a multi-channel recording, measures were made of lung volume (LV), sound pressure level (SPL), fundamental frequency (F0), semitone standard deviation (STSD), and upper and lower lip displacements and peak velocities. *Results*: Loud speech led to increased LV initiation, LV termination, F0, STSD, and articulatory displacements and peak velocities for both lips. Token-to-token variability in these articulatory measures typically decreased as SPL increased. However, rate increases were tied to increased lip movement variability. LV excursion decreased as rate increased. F0 for the men and STSD for both genders increased with rate. Lower lip displacements became smaller for faster speech. *Conclusions*: The inter-speaker differences in velocity change as a function of rate, and contrasted with the more consistent velocity performance across speakers for changes in SPL. SPL and rate change are targeted in therapy for dysarthria; therefore, the present data may lead to future research with disordered speakers. *Relevance to the current work*: This study demonstrates changes that take place with deliberately increased SPL. The current work addresses the impact of involuntarily increased SPL as a result of the Lombard effect when speaking in noise.

Dromey, C., & Shim, A. (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:10.92-4388/08/5105-1171

Objective: The purpose of this study was to assess the validity of the functional distance hypothesis, which suggests that tasks regulated by brain structures in closer anatomic proximity will interfere more than tasks regulated by structures that are in more distant regions of the brain. This was evaluated by examining whether speech, verbal fluency, and motor tasks were altered by incorporating right handed activity, presuming that right handed activity would interfere with left hemisphere language and speech demands. *Method:* Twenty young adults completed three tasks in isolation and then concurrently. They completed a speech task of repeating a sentence, a verbal fluency task of listing words that begin with the same letter, and a left handed motor task of placing pegs and washers in a pegboard. *Results:* Speech kinematic data showed that during concurrent performance of manual tasks, lip displacement and peak velocity decreased and sound pressure level increased. Spatiotemporal variability increased when the non-dominant hand was used for the pegboard tasks. There were decreases in the manual motor score when concurrently performed with the task of listing words beginning with the same letter, but not the task of repeating a sentence. *Conclusion:* This study concluded that control of concurrent tasks may be more complicated than is predicted by the functional distance hypothesis. *Relevance to current work:* This study examined the effects that two tasks may have on language performance. The authors considered whether multiple tasks affected the way the task was performed.

Howell, Peter. (2008). Effect of speaking environment on speech production and perception. *Journal of the Human-Environmental System, 11*, 6. doi: 10.1618/jhes.11.51

Objective: This review of research considered the impact the listening environment has on speaking and listening performance. It reviewed the main ways in which all sounds are affected by the environments in which they are spoken and heard. *Method*: The author reviewed how the environment affects sound and speech production—timing, frequency and intensity structure. *Results*: When noise level increases, the speakers increase their intensity (Lombard effect). This effect is seen in the current study. *Conclusions*: Compensations made for speaking in noise potentially produce a negative feedback loop where speech is louder to compensate for low voice or increased noise. Speakers can adjust their speech to fit the environment and listening audience. Masking noises have an important impact on a listener's performance. Speakers can localize sounds within a room. Listeners use stored information about what they know relative to an incoming sound in order to interpret the incoming sound. Speaking clearly can possibly alter poor acoustic characteristics in listening environments. *Relevance to the current work*: The current work evaluates the impact of potential environmental sounds on speech motor control whereas this study examined how the environment and noise impacted speech recognition and comprehension.

Huber, J., & Chandrasekaran, B. (2006) Effects of increasing sound pressure level on lip and jaw movement parameters and consistency in young adults. *Journal of Speech, Language, and Hearing Research, 49,* 1368-1379. doi: 10.92-4388/06/4906-1368

Objective: This study examines whether different cues to elicit loud speech cause changes in jaw and/or lip movement parameters or movement consistency. Differences in the results of alternate cues may suggest contrasting neural control strategies for movement. *Method:* Thirty healthy young adults participated in the study. They were asked to produce two sentences with four different instructions. They spoke at a comfortable loudness and at twice their perceived comfortable loudness. They spoke while targeting 10dB SPL above their comfortable loudness using a sound level meter for feedback, and while multi-talker noise was played. Both acoustic and lip and jaw kinematics were recorded. *Results:* The conditions where louder production was requested produced similar increases—approximately 10 dB. In the conditions where background noise was played, speech rate was slower. Changes to lip and jaw movements and consistency (relative to comfortable speaking levels) were different in the targeting condition when compared to the other loud conditions. *Conclusions:* Different movement patterns are created by different cuing for vocal loudness, and should be considered in clinical and research settings. *Relevance to the current work:* Because this work examined increased loudness in the presence of noise, the Lombard effect was considered and evaluated, as well as changes resulting from differences in neural control from specific cues. The current study addresses Lombard speech as a result of speaking in the presence of noise.

Ikeno, A., Varadarajan, V., Patil, S., & Hansen, J.H.L., UT-Scope: Speech under Lombard Effect and Cognitive Stress, *Aerospace Conference, 2007 IEEE* , vol., no., pp.1,7, 3-10 March 2007. doi: 10.1109/AERO.2007.352975

Objective: This paper addressed the needs of automatic speaker recognition in the fields of forensics, security, and speech communication. The authors studied the Lombard effect, physical task stress, emotion, and the effect of cognitive stress on individuals' speech characteristics where voice recognition systems are used to determine whether an individual's voice should be recognized as belonging to a group allowed access to a system versus those not a part of the defined group. Voice samples in controlled conditions, as well as in the presence of highway noise, large crowd noise, and pink noise were compared to simulate the accuracy of automatic speech systems in a variety of real world environments: factories, busy offices, cars, etc. *Method:* Two tests were performed—a listener test and an in-set speaker identification performance test. Lombard speech was tested using highway driving noise at 90dB SPL through open air headphones. Each speech sample consisted of three phonetically balanced sentences. Read speech was used in the study because the samples from different speakers would be more comparable. For in-set speaker ID performance, data were collected under three Lombard effect conditions (pink noise, a large crowd, and automobile noise of a car traveling 65 miles an hour down a freeway with windows ½ of the way open) and tested on an in-set speaker ID system. The system was programmed to identify whether the speech input matched a group of speakers defined in the system. Thirty speakers, 19 female and 11 male, were tested, with 15 belonging to the set granted access by the system and 15 being outside the system. *Results:* The results of the in-set speaker ID performance demonstrated that Lombard speech degraded the system's ability to correctly identify in-set speakers. In the listener test, the results indicated that the effect of the conditions on the perception of in-set speakers was significant. The effects of the speech condition were also found to be significant. *Conclusion:* The error rates of in-set speaker ID systems were degraded during the Lombard speech. It was also shown that making the duration of the speech sample longer did not improve accuracy of the in-set speaker ID system, suggesting that there are fundamental changes in the phoneme spectral structure. *Relevance to* *the current work:* This study established that there were changes to the speech output of an individual when various types of noise were present, in addition to increased intensity resulting from the Lombard effect.

Kahneman, Daniel. (1973). *Attention and effort*. Englewood Cliffs, N.J.,: Prentice-Hall.

Objective: This book included a comprehensive review of attention and effort. There was a chapter titled *Attention and Task Interference*. This chapter discussed theories about how the brain processes simultaneous tasks and the pool of cognitive resources. Chapters detailed theories of capacity and tasks that interfere with this capacity, decision bottlenecks, competition for effort, perception and effort, and the theory of interference and effort. *Relevance to the current* work: This book is relevant to the current work because we are examining the resources required for speaking tasks and whether noise would potentially influence the resource pool and thus alter speech.

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: In this study the authors compare the effects of increased loudness on lower lip movements with those of changes in speaking rate. Increased loudness which represents Lee Silverman Voice Treatment (LSVT) and changes in speaking rate are both approaches to treating hypokinetic dysarthria. *Method*: Eight adults with idopathic Parkinson's disease, eight healthy older adults, and eight young adults participated in the study. Lower lip/jaw movements were recorded and spatiotemporal index (STI) was measured. *Results:* The STI revealed that for all the speaker groups, slow speaking rate was associated with the most variability. When all of the conditions were compared, the STI values derived from loud conditions were most similar to those from habitual speech. *Conclusions*: The authors hypothesize that speaking loudly is associated with a spatial and temporal organization that is most similar to the spatial and temporal organization used in habitual speech. This may be a contributing factor to the success of the LSVT. *Relevance to the current work*: This study and the current study use the same spatiotemporal index measures to analize spatial and temporal variability.

Kozou, H., Kujala, T., Shtyrov, Y., Toppila, E., Starck, J., Alku, P., & Naatanen, R. (2005). The effect of different noise types on the speech and non-speech elicited mismatch negativity. *Hearing Research, 199*(1-2), 31-39. doi: 10.1016/j.heares.2004.07.010

Objective: This article examined the way background noise affects speech processing, and determined which noise levels did not impair brain function. The authors also analyzed the speech and the cognitive ability of individuals who live with noise in their environment. The data suggested that background noise has two effects: a transient effect and a sustained effect that is detrimental to central speech processing. *Method:* The authors cited research analyzing the effect of background noise on typical adults, the hearing impaired, the elderly, native and non-native language speakers, typical children, and children with learning disabilities. The authors examined the effects of noise types on speech processing. The noise types tested were babble noise, industrial noise, traffic noise, wide band noise, and silence. The authors examined studies of the effects of noise on the lateralization of speech processing and the effects of long-term noise on brain processes. *Results:* Noise affects the early cortical sound discrimination and the identification process for the sound that follows, hampering the perception of sound. Native and non-native listeners perform equally well at speech recognition in silence; however, native speakers do better than non-native speakers in degraded listening conditions. Background noise impairs speech perception in children with learning disabilities more than normally developing children. Background noise has an effect on the lateralization of speech processing. Long-term noise exposure affects both the early sound discrimination system and the attention regulation system. *Conclusions:* Background noise is detrimental to the brain's auditory and speech functions. Certain members of the population are at greater risk, including children, the elderly and non-native language speakers. Background noise that is continual impairs speech perception, modulates the activity of neural structures involved in speech processing, and may reorganize speech sound discrimination functions between the two cerebral hemispheres. Noise may cause long term effects on the central auditory processing, cortical speech discrimination, and attention control. *Relevance to the current work:* The authors examined the effects of various noise conditions on speech perception, laying the groundwork for understanding whether noise conditions have an effect on speech motor control.

Kujala, T., & Brattico, E. (2009). Detrimental noise effects on brain's speech functions. *Biological Psychology, 81*(3), 135-143. doi: 10.1016/j.biopsycho.2009.03.010

Objective: This study reviewed evidence which supports the idea that background noise has both transient and sustained detrimental effects on central speech processing. This is important because background noise has become part of everyday life in society and affects the ability to concentrate and communicate. People at risk for greater effects from background noise include the elderly, children, and non-native speakers. *Method*: The authors reviewed research on the effects of various noise types on central speech processing including: hemispheric reorganization, long term effects of noise exposure, speech processing, and attention control. *Results*: Noise levels that are below the threshold to cause peripheral hearing damage can have a lasting effect on speech brain function, perception, attention control and, as a result, behavior. Children are at an increased risk because noise both degrades speech perception and adds increased load to cognitive processing. Brain imaging studies have demonstrated that noise may be enhancing or suppressive. Some functions related to speech perception become redistributed from the left to the right hemisphere. In noise, speech sounds are processed as acoustic events and are primarily analyzed in the right hemisphere. Speech is especially vulnerable to uncontrolled noise, which can become confounding. *Conclusions*: Results suggest that the neural mechanism for processing speech input and output is particularly vulnerable to noise. Long term effects of noise were observed wherein the lateralization of brain function to the right hemisphere to process speech in noise does not immediately change back to the left hemisphere when the noise ceases. The evidence also indicates that background noise is detrimental to the brain's auditory and speech functions. *Relevance to the current work*: The current study attempts to identify noise changes on speech kinematics in light of evidence suggesting neural changes to the language processing and speech production of individuals in the presence of noise.

Kujala, T., Shtyrov, Y., Winkler, I., Saher, M., Tervaniemi, M., Sallinen, M., Teder-Salejarvi, W., Alho, K., Reinikainene, K., & Naatanen, R. (2004). Long-term exposure to noise impairs cortical sound processing and attention control. *Psychophysiology, 41*(6), 875-881. doi: 10.1111/j.1469-8986.2004.00244.x

Objective: The authors presented a systematic and long-term study examining the effects of noise on cortical function. *Method*: Eight shipyard workers and two preschool teachers were selected because of their ongoing exposure to noisy work environments. The stimulus sequences included a standard syllable /pa/, a deviant syllable /ka/ and novel sounds including a door slamming and telephone ringing. Synthesized speech sounds of 185ms in length and novel sounds of 200ms in length were used. The sounds were presented via two loudspeakers facing the same direction as the participant. Conditions were randomly presented in silence and then in the presence of background noise presented by the loudspeakers. Signal to noise ratio was 15 dB. EEG signals were recorded while the participant, playing a computer game with a high visual tracking demand, was instructed not to pay attention to the auditory signal. *Results*: Computer game performance of the participants who were not exposed to noise did not decline in the presence of repetitive and standard stimuli. Performance declined during exposure to the deviant and novel sounds. In the case of the noise exposed participants, both deviant and novel sounds significantly reduced performance on visual tracking tasks in the silent condition, while only novel sounds decreased performance in the noise condition. *Conclusion*: The study demonstrated that long-term noise exposure impairs central sound discrimination and increases distractibility to environmental sounds. This was apparent in behavioral, oral, and brain responses. The results suggest the possibility that after long-term exposure to noise, the neurons do not adequately recover from the depressing effect of the noise, but remain in the same state as they were during the noise exposure. *Relevance to the current study*: The present study aims to determine the impact of noise on lip kinematics, further investigating the effect of noise on the brain's speech centers.

Lieberman, P. (2001). Human language and our reptilian brain: The subcortical bases of speech, syntax, and thought. *Perspectives in Biology and Medicine, 44*(1), 32-51.

Objective: This book discusses theories regarding the acquisition of language and the related brain structures. The author refutes previous theories by Noam Chomsky that attribute language development to a genetically transmitted brain module or organ that is responsible for syntax. The author believes that language is an acquired and learned skill and not an instinct. Language learning is, therefore, a function of the social environment internalized through the process of learning involving the basal ganglia. *Relevance*: The author believes that human speech and language are integrated with other aspects of cognition, motor control, and emotion. This is relevant because the current study attempts to identify if noise acts as a cognitive distractor task affecting motor control for 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. doi:10.1044/jslhr.4302.560

Objective: The authors' purpose was to investigate the possible influences of utterance length and complexity on speech movements. This was done by assessing the effects of increased processing demands on articulatory movement stability. *Methods*: Eight five-year old children and eight young adults repeated a 6-syllable phrase in a baseline condition (isolation), and embedded in sentences of high and low syntactic complexity. Lower lip movements were analyzed to produce the spatiotemporal index (STI), which reflected the stability of lip movements across ten phrase repetitions. *Results*: The STI was significantly increased for the phrase spoken in a complex sentence compared to the baseline condition. The STIs of the adults were consistently lower than those of children. *Conclusions*: Speech motor planning and execution are affected by processes often considered to be remote from the motor output stage. *Relevance to the current work*: The current work examines the effect of noise rather than lexical complexity on articulatory movement stability.

McDowd, J. M. (2007). An overview of attention: Behavior and brain. *Journal of Neurologic Physical Therapy, 31*(3), 98-103. doi: 10.1097/NPT.0b013e31814d7874

Objective: This article provided an overview of attention and the different ways it has been studied in the field of psychology. A general review of theories which focus on the concepts of attention resources and attention effort was provided. Attention was defined and expanded upon within four categories including: selective attention, divided attention, attention switching, and sustained attention. Posner's attentional network and Mesulam's attentional matrix were reviewed. *Relevance to the current work*: The current study aims to address the impact of noise on speech motor control. In this work the noise is potentionaly a distraction that requires selective attention to complete the speaking task without degraded performance in the noise conditions.

McLeod, P. (1977). A dual task response modality effect: Support for multiprocessor models of attention. *Quarterly Journal of Experimental Psychology, 29*, 16. doi: 10.1080/14640747708400639

Objective: The author conducted this experiment to test the multiprocessor model of attention, which suggests that the brain may have multiple processors that can be dedicated to multiple tasks. *Methods*: This research was divided into two experiments. In experiment I, two groups of 11 men performed a continuous visual input/manual output task simultaneously with a two-choice tone identification task. One group of men responded vocally to tones while the other responded with the hand not involved in the continuous tracking task. In experiment II, the same manual tracking task was combined with a mental arithmentic task at two levels of difficulty. *Results*: In experiment I, performance on the continuous task was slightly worse when the two-choice responses were manual. The likelihood of response production on the continuous task was affected by the production of manual responses but not by the production of vocal responses. In experiment II, tracking performance was independent of the difficulty of the arithmetic tasks. *Conclusion*: In experiment I it was concluded that although the two manual responses were produced by a single limited capacity process, the manual and vocal responses were produced by independent processes. In experiment II it was concluded that there was support for a multi-processor approach to attention as opposed to single channel models. *Relevance to the current work*: Data regarding theories of attention are relevant because the current work aims to identify whether various noises are sufficient to alter attention to and thus execution of a speaking task.

Mesulam, M. M. (2000). *Principles of behavioral and cognitive neurology* (2nd ed.). New York: Oxford University Press.

Objective: This book provided both a clinically and scientifically directed approach to the biological foundation of human mental functioning as it relates to behavioral neurology, neuropsychiatry, and neuropsychology. The book identified major cognitive domains including frontal lobe functionality, attention and neglect, memory, language, prosody, complex visual processing, and object identification. Mesulam's matrix of attention was defined. *Relevance to the current work*: Theories of attention and neglect are relevant to the current work in that they postulate how attention works and what might be happening when it is impaired. Attention is a key component in the current work.

Moss, F., Ward, L. M., & Sannita, W. G. (2004). Stochastic resonance and sensory information processing: A tutorial and review of application. *Clinical Neurophysiology, 115,* 267-281. doi: 10.1016/j..clinph.2003.09.014

Objective: This review considered the stochastic resonance phenomena that are observed in the sensory system and illustrate how noise (referred to as a random process) added to a subthreshold stimulus can improve perception and sensory information processing. *Method:* A literature review of current research was conducted from which relevant information was drawn. *Results:* The stochastic resonance phenomenon occurs when a nonlinear system is presented with noise and a threshold and subthreshold information containing stimulus. The noise, provided it is at the right level, will increase the subthreshold information containing system so that it is understandable at threshold. If the noise is too great it will interfere with the information containing stimulus and not boost it to a discernable level. There is evidence that stochastic resonance may play a role in brain functions, such as detection of weak signals, synchronization and coherence between neural assemblies, phase resetting, carrier signals, animal avoidance, and feeding behaviors. *Conclusions:* The stochastic resonance theory fits into theories of brain function and neural models. Evidence and information gathering is in an early stage and more research is needed in the areas of biology and medical science. *Relevance to the current work:* This study examined the effect of noise on information detection in a signal, automatic processes that boost the signal to account for noise interference, and neural processes that occur naturally to adjust for a weak signal in the presence of noise. The current study considers the effect of noise on speech movements.

Mukherjee, D., Levin, R. L., & Heller, W. (2006). The cognitive, emotional, and social sequelae of stroke: Psychological and ethical concerns in post-stroke adaptation. *Topics in Stroke Rehabilitation, 13*(4), 26-35. doi: 10.1310/tsr1304-26

Objective: The purpose of this article was to describe the needs of the stroke rehabilitation population, including fluctuating emotion, executive function, volition, self-agency, and depression. It also explored the various facets of attention and where they are located in the brain. *Method*: The authors reviewed the emotional, social, cultural, cognitive, and language deficits associated with stroke. *Results*: Psychological aspects of post stroke changes include depression, anxiety, and social isolation. Executive function, self-agency, and volition may also be impacted by stroke. Fluctuations in emotional, cognitive and physical ability may result in alterations in identity and personality. *Conclusions*: Cognitive and emotional functional changes result in many quality of life changes including social isolation, changes in personal relationships, impaired attention, and changes in transportation and employment. Understanding the causes of these changes as well as the consequences impacts the recovery from damage to the brain. *Relevance to the current work:* The authors of the article detailed the multiple congnitive functions that make up attention and found that each function is housed in different components of the brain. Therefore, while patients recovering from a stroke may have different sites of lesion, they may have very similar attention difficulties. The current work addresses potential deficits to attention in a speaking task in the presence of noise in a typical population, with potential inferences for a disordered population, like those who have suffered a stroke.

Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience, 35*, 73-89. doi: 10.1146/annurev-neuro-062111-150525

Objective: The purpose of this follow-up article was to update an article written in 1990 about the attention system of the brain. In the original article, the authors introduced the integration of behavioral, cellular, and molecular methods to address typical problems in attention research. The article adds new research on the subjects of orienting and executive function and how they support functions in other brain regions. *Method*: The authors outline some of the significant advances of the past 20 years as they relate to their origional framework. *Conclusions*: New research findings have produced increased understanding of pathology and intervention. The networks of attention include alerting, orienting, executive control, self regulation, and training. *Relevance to the current work:* The current work studies the impact of noise on a participant, who is required to use attention to complete a speaking task in the presence of noise—a potential detriment to task-specific attention.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*, 25-42. doi: 10.1146/annurev.ne.13.030190.000325

Objective: The purpose of this article was to examine the concept of attention as it pertains to human performance in the realm of experimental psychology. *Method*: The authors examined known research regarding the attention system of the brain to present a higher level examination of cognition, a physiological analysis and the identification of the active anatomical areas that appear to be the foundation of the selection of information and conscious processing of attention. *Results*: The data processing systems that perform operations of specific inputs are anatomically separate from the attention systems of the brain. Attention is executed by a network of anatomical areas in the brain, which can be identified in cognitive terms. *Conclusions*: The attention system in the brain is similar to the motor and sensory systems in that it interacts with other parts of the brain while maintaining its own identity. *Relevance to the current work*: This work laid the foundation for selective attention and the anatomical areas of the brain that were potentially involved. The present study leans heavily on the concept of selective attention and the ability to ignore a noise stimulus or note how the noise degrades the performance or the selected (speaking) task.

Roberts, W., Fillmore, M. T., & Milich, R. (2011). Separating automatic and intentional inhibitory mechanisms of attention in adults with attention-deficit/hyperactivity disorder. *Journal of Abnormal Psychology, 120*(1), 223-233. doi: 10.1037/a0021408

Objective: The purpose of the study was to demonstrate the fundamental distinction between automatic and intentional mechanisms of inhibitory control. More specifically, the study addressed whether inhibitory control deficits identified in adults with ADHD are based on the type of inhibitory control response (automatic or intentional). *Method*: The study compared 30 adult participants with ADHD between the ages of 19 and 30 with 27 adults with no history of ADHD. Patients with a history of mental illness were excluded from the study. Participants were given a delayed ocular response task to measure inhibitory control of attention. Participants' ability to intentionally inhibit the propensity to make a reflexive saccade toward the sudden appearance of a visual stimulus on a computer screen was measured. Saccadic interference tasks were designed to test automatic inhibitory control of attention by measuring the participant's capability to filter an irrelevant stimulus while carrying out a saccade toward a target location. *Results*: The participants with ADHD produced significantly more premature saccades than the control group. Saccadic interference tasks demonstrated that distractor stimuli significantly slowed the reaction time of both groups. The ADHD and control groups had similar saccadic interference results. *Conclusions*: Adults with ADHD are less able to inhibit a reflexive saccade toward the sudden appearance of a stimulus in their peripheral vision. Saccadic interference tasks demonstrated that the ADHD and control group had similar measures of automatic inhibitory control. These results suggest a difference between automatic and intentional inhibitory deficits in adults with ADHD. *Relevance to the current work*: The authors illustrated automatic and intentional inhibitory differences between a typical population and those with ADHD. These differences impact the individual's control of attention. The current study endeavors to identify how well typical adults use aspects of attention to filter out the distraction of noise and maintain attention on a speaking task.

Schmidt, C. F., Zaehle, T., Meyer, M., Geiser, E., Boesiger, P., & Jancke, L. (2008). Silent and continuous fMRI scanning differentially modulate activation in an auditory language comprehension task. *Human Brain Mapping, 29*(1), 46-56. doi: 10.1002/hbm.20372

Objective: The purpose of this study was to illustrate that an event-related task design can be properly combined with a clustered temporal acquisition technique in an auditory language task. This was done to mitigate the confounding noise factor of traditional fMRI scanning during language tasks. *Method*: Fifteen volunteers underwent two distinctly separate auditory language tasks with fMRI and a newly developed *Silent MRI* technique that was built on a clustered temporal acquisition technique. *Results*: The silent MRI technique was accompanied by significantly stronger responses along the temporal plane. Conversely, bilateral insulae engage more strongly during continuous scanning. Cortical activation in subportions of the supratemporal plane varies depending on the protocol. The middle part of the temporal plane reveals significantly stronger leftward asymmetry during the silent MRI technique. *Conclusions*: The noise which accompanies the fMRI scanner is processed in the right hemisphere of the brain and auditory language task function shifts to the right hemisphere as well, making it difficult to determine neuronal allocation for language tasks without confounding noise. The silent technique was used effectively to map the asymmetry of language processing in the left hemisphere of the brain without engaging the right hemisphere and thus yielded more accurate results for the task. *Relevance to the current work*: The current work uses a foundation of language allocation in the brain and lateralization of function with noise to test whether noise will influence the way speech is produced.

Shtyrov, Y., Kujala, T., Ahveninen, J., Tervaniemi, M., Alku, P., Ilmoniemi, R. J., & Naatanen, R. (1998). Background acoustic noise and the hemispheric lateralization of speech processing in the human brain: Magnetic mismatch negativity study. *Neuroscience Letters, 251*(2), 141-144. doi: 10.1016/S0304-3940(98)00529-1

Objective: This study examined the impact of different types of white noise on the cortical mechanisms of speech processing. In reviewing four previous studies, the authors found that while it was determined that different types of noise change the lateralization of speech processing, there was no direct measurement of brain activity to confirm this hypothesis. Specifically, the authors attempted to confirm that the presentation of noise increased the involvement of the right hemisphere in speech perception. *Method:* Using a whole-head magnetometer, the authors measured brain activity of 11 healthy right-handed participants aged 21-28 with normal hearing when presented with a standard stimulus delivered repetitively at varying intervals. Stimuli were presented under three conditions: in silence, and in two types of white noise. The *Results:* In the silent condition, mismatched negativity (MMN) dipole moments were larger in the left hemisphere in all tested subjects. However, when presented in noise, larger MMN dipole moments were recorded in the right hemisphere in all but two of the subjects. *Conclusion:* The data suggest that when masked by noise, speech signal discrimination reverts from the right to the left hemisphere of the brain. This confirmed earlier studies, through brain-activity evidence, that a redistribution of lateralization of the speech-sound discrimination function occurs in the presence of noise. *Relevance to the current work:* This work confirms the neural lateralization and changes in processing speech in noise. The current work seeks to further determine the effect of noise on the motor control of speech.

Shtyrov, Y., Kujala, T., Palva, S., Ilmoniemi, R. J., & Naatanen, R. (2000). Discrimination of speech and of complex nonspeech sounds of different temporal structure in the left and right cerebral hemispheres. *NeuroImage, 12*(6), 657-663. doi: 10.1006/nimg.2000.0646

Objective: The purpose of this study was to determine potential differences between the processing of speech and complex nonspeech sounds in left and right cerebral hemispheres. *Method*: The authors measured the magnetic correlate of the mismatch negativity, or the automatic and direct response of the brain, elicited by speech sounds and comparable complex nonspeech sounds with fast and slow acoustic transitions. Sixteen healthy participants with normal hearing and no history of neurological illness were presented binaurally with a repetitive and standard stimulus with a 15% chance of a deviant stimulus. The subjects were presented with three different sets of acoustic stimuli in three different conditions. *Results*: The results suggest that the right hemisphere is predominant in the perception of slow acoustic transitions. Neither hemisphere was dominant in the discrimination of nonspeech sounds with fast acoustic transitions. However, it was found that the perception of speech stimuli with comparable rapid acoustic transitions was dominant in the left hemisphere. *Conclusions*: It is speculated that acoustic templates or long-term memory traces for speech sounds are formed in the left hemisphere, necesitating left hemisphere dominance for the processing of speech stimuli. *Relevance to the current work*: This study provides evidence that speech and noise are not processed the same way in the brain. The present study aims to evaluate the effect of various noise on motor speech.

Smith, A., Goffman, L., Zelaznik, H. N., Ying, G., & McGillem, C. (1995). Spatiotemporal stability and patterning of speech movement sequences. *Experimental Brain Research, 104*(3), 493-501. doi: 10.1007/BF00231983

Objective: The purpose of this study was to identify the stability and patterns of speech movement sequences at different rates of speech. *Method*: Adults completed a phrase repetition task at normal, fast and slow rates of speech while their lip movements were recorded. The movements were analyzed using an index of spatiotemporal stability derived from adding the standard deviations calculated across amplitude and time normalized displacement records. The relative time of occurrence of the peak velocity of three middle opening movements of the utterance was measured, as were the normalized displacement waveforms. *Results*: It was found that normal and fast rates of speech produced a more stable movement execution pattern as compared to a slow rate of speech. The analysis of velocity peaks indicated that the relative timing of three movements does not remain consistant across changes in speech rate. The timing of the middle opening gesture shifted to a later time as utterance duration increased. The pattern recognition techniques performed on the normalized displacement waveforms identified three distinct movement patterns for each rate of speech. *Conclusions*: The authors found that slow speech patterns have less stability and are not as smooth as normal or fast speech patterns. The relative timing of events does not remain constant across speech rates. It was concluded that within a subject, three distinct patterns exist for the different rates of speech analyzed. This suggests that speech rate is a global parameter that affects the whole command sequence for an utterance. *Relevance to the current work*: In this and the current work, STI was calculated by taking the sum of the standard deviations from 50 equally spaced points along the normalized waveforms. This allowed the STI to measure consistency of speech articulation over multiple repetitions, where a smaller number reflects lower variability.

United States. Department of Transportation. Federal Aviation Administration. Office of Aviation Medicine & University of Ilinois at Utbana-Champaign. Aviation Research Laboratory. (1998). *Conformal flight path symbology for head-up displays: Defining the distribution of visual attention in three-dimensional space* by C.D. Wickens and P.M. Verners. Washington DC: Federal Aviation Administration. (Final technical report) (ARL-98-5/NASA-98-1)

Objective: The purpose of this study was to determine the effect of a head-up or head-down display, image intensity, and clutter on the allocation of attention. *Method*: Two experiments were conducted. In the first experiment a low-fidelity simulation with both near-domain and far-domain instrumentation were presented at the same distance visually. The detection of flight command changes and the maintenance of the flight path were recorded. The second experiment was conducted with pilots viewing far-domain imagery or airborne targets on a head-up display at the same optical distance, and head-down imagery at a near distance typical of the instrument panel. The amount of clutter was also varied; the image contrast ratios were considered equal in the head-up and head-down viewing conditions. *Results*: Detection of commanded flight changes and maintenance of the flight path flight were typically better in the head-down condition, which may be attributed to the superior image contrast ratios in that condition. However, target detection was greater with the head-up display, indicating an attentional tradeoff. In the second experiment, flight performance was comparable in the head-up and head-down positions. In contrast, detection of commanded changes or near-domain versus far-domain targets was better in the head-up position, indicating the head-up benefit of reduced scanning. Adding clutter to the head-up display decreased detection of events in both head-up and head-down locations. *Conclusions*: The data provided reduced support for the idea that attention was modulated in depth (near vs. far domains), but instead indicated that attention was modulated between tasks. *Relevance to the current work*: The authors examined factors that modulate attention, including the placement of the display, contrasts, and the amount of information or clutter. This sets a foundation for identifying factors which enhance or suppress the control of 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:____________