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P300 Event-Related Potentials to a Phoneme Discrimination Task Requiring a Motor Response

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ABSTRACT

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Speech perception typically takes place within the auditory cortex as evidenced by data collected using quantitative electroencephalography (qEEG). The purpose of this study was to determine if motor responses influence speech perception. We examined P300 event-related potentials during oddball stimulus recognition tasks that either required or did not require a motor response. Based on a review of the literature, it was hypothesized that similar areas of the brain would be activated in both the motor response task and the same task without a motor response immediately following the button-push condition. Two syllables, /ba/ and /ga/, were presented to 20 native English speakers (10 females and 10 males) between the ages of 19 and 30 years. An oddball paradigm consisting of standard and deviant stimuli was presented in three trials: passive listening, mental counting, and button-push. Participants were randomly assigned an order to the trials for passive listening and mental count; however, the button-push response was completed second each time. Data from event-related potentials were recorded for each participant using qEEG and combined across participants to create grand averaged waveforms. Cortical regions of activation were identified and compared across conditions. Results showed that different cortical areas were activated when the mental counting and passive listening conditions were done before and after the motor response condition. Requiring a more complicated response than is typically used to discriminate phonemes, such as with the button push response, may alter speech perception based on the cortical regions activated as measured through source localization. Further research on latencies and amplitudes of the even-related potential (ERP) waveforms is needed to determine how speech perception changes.

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DESCRIPTION OF THESIS STRUCTURE

This thesis, *P300 Event-Related Potentials to a Phoneme Discrimination Task Requiring a Motor Response*, is part of a larger 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 informed consent for participants is presented in Appendix A and an annotated bibliography is presented in Appendix B.

Introduction

Humans possess the unique ability to recognize meaning and intention from auditory speech stimuli. Although research has demonstrated how vowels and consonants are recognized and given meaning compared to non-speech auditory stimuli, a definitive explanation of this process is still absent (Diehl, Lotto, & Holt, 2004). Research using behavioral and electrophysiological measures has been used to grant greater understanding of speech perception. Speech perception is influenced by a variety of factors, including semantic and syntactic complexity, loudness, pitch, and listener training (Lasky & Chapandy, 1976). These components of speech perception can be measured using listener reporting (ie., auditory discrimination tests) and can provide insight into behavioral speech perception. Auditory discrimination tests are designed to measure an individual's phonological awareness—the ability to focus on and manipulate phonemes within spoken words. This includes the ability to compare and contrast speech sounds. Although results are accurate, these types of tests do not provide greater detail on the neurophysiological process occurring during phoneme discrimination; however, electrophysiological measures expound on the brain's physiological response and source localization of brain activity during speech perception. Understanding this process in greater detail in neurotypical individuals may allow for future research and clinical application in individuals with neurological damage.

Neurophysiologic Measures of Auditory Phoneme Discrimination

Functional magnetic resonance imaging. Functional MRI (fMRI) is a neurophysiological measure that provides detailed spatial data of the brain during activation tasks. When parts of the brain are activated to perform various tasks, they require oxygenated blood to carry out the function. Functional MRI measures the movement of oxygenated and

deoxygenated blood within the brain during various tasks. Sekiyama, Kanno, Miura, and Sugita (2003) conducted a study using fMRI and positron emission tomography (PET), an additional brain imaging technique, which included an audio-only condition. During this condition, Sekiyama et al. observed activation in the temporal cortex bilaterally containing the primary auditory cortex. Activation was observed along the superior temporal sulcus, including Brodmann area 22 (BA22) and overlapping the region of Wernicke's area. Additionally, Grosvald and Corina (2012) examined the functional organization of the human auditory cortex using fMRI. Results showed the inferior parietal lobe has a role in processing task-relevant and irrelevant auditory information. These results provide clarity on the cortical regions activated during auditory comprehension, which is evidence of where speech perception is occurring.

   Quantitative electroencephalography. Another method to monitor brain activity during speech perception is quantitative electroencephalography (qEEG). The brain communicates within itself and with other systems in the body through electrical signals or impulses that are sent via neurons. These electrical signals emit energy that can be measured using electrodes placed on or under the surface of the scalp. qEEG differs from EEG in that individuals carry out targeted tasks in order to elicit specific neural responses during EEG measurement. Although qEEG gives more accurate temporal data than spatial data, qEEG can still provide valuable, if more general, information on the location of activity in the brain during auditory discrimination tasks. Location is determined by noting which electrodes receive signals during tasks. Aerts et al., (2017) found that auditory phoneme discrimination is supported by both auditory and motor regions in a fronto-temporo-parietal cortical network using qEEG. Aerts et al. found this by using an oddball paradigm, in which a standard auditory stimulus is presented with an intermittent deviant stimulus throughout. When a deviant stimulus is presented, responses are

evoked in the auditory cortex to reveal both the location and timing of the brain's response to the deviant stimulus. These responses are classified as event-related potentials (ERPs) and they are the average of signals received during the qEEG. These ERPs are defined by their negative or positive polarity and the latencies of ERPs provide temporal information on processing activity in the brain in milliseconds. Additionally, the amplitudes of the ERPs signify the amount of neural resources allocated to specific cognitive processes (Duncan et al., 2009). Two common ERPs analyzed when studying speech perception are the mismatch negativity (MMN) and P300, which will be discussed below.

Sharma and Dorman (2000) located the primary generator sites for MMN and N100, both ERPs, as the auditory cortical and thalamic areas during presentation of auditory speech stimuli. Mismatch negativity is a valuable tool in determining auditory processing abilities in both children and adults. According to Kraus, McGee, Sharma, Carrell, and Nicol (1992), "the mismatch negativity (MMN), which occurs at roughly 200 msec after stimulus onset, indicates whether the auditory system has distinguished between two different auditory signals. This event-related potential (ERP) may become a useful tool in the diagnosis of pathology in the central auditory system." Csépe, Osman-Sági, Molnár, and Gósy (2001) found that the MMN was altered in individuals with aphasia. Deficient processing of contrasting features based on voicing, manner of articulation, and place of articulation was observed in individuals with damage to their language processing network. Event-related potentials provide a detailed tool in measuring latency of response to stimuli and relation between different areas of the brain. When paired with behavioral responses, ERPs also provide insight into accuracy of responses.

The P300 is an event-related potential that peaks around 300 ms after the onset of a task-relevant stimulus using an oddball paradigm. P300 is a sensitive measure of the capacity to

allocate attentional resources. Amplitudes are decreased as listeners become habituated to repetitions and amplitudes are larger when target stimuli require a response. These are two factors that influence auditory processing.

Another factor that may alter speech perception and processing is stimulus complexity. In a study done by Cacace and McFarland (2003), tone glides were more difficult to discriminate than pure tone stimuli. An increased P300 amplitude was seen in response to the target stimulus in comparison to the standard stimulus, indicative of a need for increased cortical resources, such as attention and discrimination skills. Tampas, Harkrider, and Hedrick (2005) examined how the MMN and P300 responses are influenced by the phonetic characteristics of a stimulus. Results showed that speech and non-speech stimuli were processed differently as evidenced by behavioral measurements, MMN, and P300 amplitudes and latencies. Additionally, Dehaene-Lambertz (1997) found that phonemic stimuli presented must be within the subject's native language to elicit significant event-related potentials, suggestive of phonemic characteristics being stored within the listener's sensory memory. In a study done by Domahs, Kehrein, Knaus, Wiese, and Schlesewsky (2009), an ERP effect on N400 was produced by well-formed and ill-formed non-word stimuli in comparison to existing words in the speaker's native language, suggestive of non-word stimuli creating an adverse effect on speech perception.

Multiple Modalities in Speech Perception

Altering the cognitive load during an oddball paradigm response task by introducing additional required modalities of response may alter both the spatial and temporal components of speech perception. The use of multiple modalities to comprehend speech has been shown to improve language comprehension. Although humans are able to understand words without visual input, auditory-visual perception has been shown to improve language recognition and

comprehension (Sumby & Pollack, 1954) even when the acoustic information is clear (Reisberg, McLean, & Goldfield, 1987). In a study done by Schmidt-Kassow, Thöne, and Kaiser (2017), coupling a motor activity to auditory processing enhanced the efficiency of the processing. P300 amplitudes increased when motor and auditory components were synchronous. This study used silent counting with an oddball paradigm to analyze participants' auditory processing both with and without motor movement that was not dependent on recognition of the deviant stimulus. Motor movement was found to improve phonemic encoding skills. The current study will employ a motor response in recognition of the deviant stimulus during an oddball paradigm to determine if the location of phonemic encoding is altered in comparison to silent counting with no motor response. This study provides evidence towards the hypothesis that motor movement used to signal recognition of the deviant stimulus will improve phonemic processing.

Alexander et al. (2005) reported that by coupling an ERP auditory oddball discrimination task with listener's self-evaluation following each stimulus reported through a button-push response, larger P300 amplitudes and longer latencies were observed, meaning more cortical resources were used during this condition. No change in the P300 response was shown when participants were only asked to maintain a mental count of deviant phonemes heard. Although these results do not show direct improvement of language recognition and comprehension, they do reveal that an additional modalities used to report the oddball stimuli also increased the cortical resources necessary to accomplish it.

Statement of Purpose

The purpose of this study is to determine using event-related potentials during phoneme discrimination tasks if a motor response that is dependent on recognition of the deviant stimulus during these tasks influence speech perception in comparison to the same task with no motor

response completed directly after the condition requiring a motor response. This study will analyze location of neural activation as an initial step in the research process. Further analyzation may be done on differences in latencies and amplitudes of the ERP waveforms during the different conditions. Based on a review of the literature, it is hypothesized that similar areas of the brain will be activated in both the motor response task and the same task without a motor response immediately following the button-push condition.

Requiring a more complicated response than is typically used to discriminate phonemes, such as with the button push response, may improve speech perception as measured through source localization. Individuals who have experienced neurological damage may benefit from the additional cognitive load to improve their ability to perceive language differences.

Method

Participants

Twenty individuals (10 men and 10 women) between the ages of 19 and 30 years participated in this study (mean age 24.4). Data from one male and one female participant were not included in the results due to poor EEG recordings. All participants were required to be native English speakers (Dehaene-Lambertz, 1997; Domahs et al., 2009) and have no reported history of cognitive, learning, or neurological impairments (Csépe, Osman-Sági, Molnár, & Gósy, 2001). All participants passed an initial hearing screening showing that their hearing is within normal limits bilaterally. Hearing screenings met the specifications set forth by the American Speech-Language-Hearing Association (ASHA, 1990). Normal pure tone thresholds are defined as ≤ 15 dB HL for octave intervals between 250-8000 Hz and threshold differences between ears ≤ 5 dB HL.

Each participant read and signed an informed consent document approved by the Institutional Review Board at Brigham Young University before participating in the study. In addition to meeting the ethical requirements set by Brigham Young University, this study also met the ethical requirements as stated in the Declaration of Helsinki (World Medical Association, 2008).

Instrumentation

Stimulus preparation. The phonemes /ba/ and /ga /were selected by recording those phonemes from a series of four college age, female, native English speakers. The auditory stimuli were recorded using a linear 16-bit, 48 KHz sample rate and an external Sony ECM-XM1 microphone placed approximately 30 cm from the speaker's mouth using a windscreen. Three graduate students in speech-language pathology judged each speaker on a scale of one to five. The speaker with the highest score for auditory recordings was selected. The recordings for that speaker were re-evaluated for the best phoneme sample by rating each phoneme for auditory and visual clarity, again using a scale of one to five for each modality. The final phoneme selection was edited using Adobe Premiere CS5 and Adobe Audition CS5. The phonemes were balanced for equal loudness using an adapted loudness paired-comparison paradigm (Yost, 2007). The final auditory recordings were 16 bit, 48 KHz.

Instrumentation for initial hearing screening. Instrumentation that was used for the hearing screening included a Grason-Stadler model GSI-1761 audiometer with headphones for the auditory testing. Also, during data acquisition, the test stimuli were presented to the participant via the Grason-Stadler audiometer via insert phones. Hearing screenings were conducted in a double-walled, sound treated test booth. Noise levels were within the limits as specified by the American National Standards Institute (ANSI) S3.1-1999 R2008 Maximum

Permissible Ambient Noise Levels for Audiometric Test Rooms for ears uncovered (ANSI, 2008).

Stimuli

Auditory stimuli were used in this study. Two naturally spoken syllables (/ba/ and /ga/) were presented to the participant in three trials each lasting eleven minutes. The phonemes were presented through insert phones while the participant was seated in a soundproof booth.

Procedure

Stimulus presentation and behavioral data acquisition. The auditory stimuli were placed on a personal computer (PC) and interfaced with the ePrime company and NeuroScan company software. The ePrime software was used to trigger the auditory stimuli and to mark the stimulus type on the streaming EEG using the NeuroScan software. Three stimulus sequence files were created. Each sequence contained a randomized list of phonemes, with 81 deviant phonemes (/ga/) and 459 standard phonemes (/ba/) presented. Each participant listened to three trials each lasting 11 minutes. Prior to each 11 minute trial, participants listened to a 1 minute practice trial. Condition 1 included the participant listening to the stimuli either passively or mentally counting each deviant phoneme. In Condition 2, the participant was instructed to press a button every time they heard the /ga/ phoneme instead of /ba/. During Condition 3, the participant again either listened passively or mentally counted each time they heard /g/ instead of /ba/ depending on which condition they completed first. The order of Condition 1 and 3 was randomly selected for each participant; however, Condition 2 was always presented as Trial 2.

The auditory stimulus was presented binaurally via Etymotics 3A insert earphones at 45 dB HL routed from the PC through a GSI-61 company audiometer. Prior to the presentation of the stimuli in each condition, participants were read the following instructions:

Condition 1. In this block, you will hear a series of syllables, "ba" and "ga." You do not need to respond to anything you hear. You will see an X on the screen. Please direct your gaze at the X. This first trial will take about one minute. Are there any questions? We will start the one-minute practice.

Condition 2. In this block, you will hear a series of syllables, "ba" and "ga." Please press the green button every time you hear the syllable "ga." You will see an X on the screen. Please direct your gaze at the X. This first trial will take about one minute. Are there any questions? We will start the one-minute practice.

Condition 3. In this block, you will hear a series of syllables, "ba" and "ga." Please count the number of times you hear the syllable "ga." You will see an X on the screen. Please direct your gaze at the X. This first trial will take about one minute. Are there any questions? We will start the one-minute practice.

The experimental duration lasted approximately 40 minutes, including a two-minute break between Trials 2 and 3 if requested by participants.

Electroencephalography data collection. Participants sat quietly in an audiometric test room during the acquisition of the data. Participants were fitted with an electrode cap (Electro-Cap International, 2003) having 64 silver-silver chloride electrodes resting against the scalp and distributed according to the 10-20 International System (Jurcak, Tsuzuki, & Dan, 2007). In addition to the scalp electrodes, six electrodes were placed on the right and left mastoid process (linked-mastoid references), the outer canthus of the right and left eyes, and one above and below the supraorbital foramen of the left eye. These additional six electrodes were placed to monitor activity and movement of the eye and facial muscles. Electrode impedances of the cap did not exceed 3000 ohms.

Compumedics software (2008) was used for EEG data collection and initial analysis (NeuroScan 4.5). NeuroScan Stim 2 software was used for stimulus presentation. In addition, CURRY 7 (Compumedics Neuroscan, 2008) software was used for cortical localization of the electrophysiological responses, post-hoc. Participants' responses and EEG were recorded and stored on a secure digital computer.

Data Analysis

Recordings were individually examined. Epochs were created from the raw EEG data. Prior to averaging the epochs, the CURRY 7 software was used to remove artifacts such as eye and jaw movement (Compumedics Neuroscan, 2008). Averages of the ERP data were calculated for each block of stimuli for each participant. Further averaging of individual ERP files for each stimulus were completed for a total of ten grand averages of the ERPs. Dipoles, cortical source sites of electrical activity, were identified using CURRY 7 software for the grand averaged ERP files (Compumedics Neuroscan, 2008; Näätänen, 2008). Locations of each dipole were compared between groups and the grand average for all deviant and standard responses within each block of stimuli. The brain activity as measured by the electrodes from the grand averaged ERP files was used to determine the dipole locations at latency epochs.

<div align="center">

Results

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Event-related potential averages were calculated for each condition of stimuli (standard and deviant) for each participant. Grand averages of participants were calculated for each condition. Because the passive listening task and mental counting were done either before or after the motor response trial, the grand averaged ERP files were calculated first as a whole and then split into two groups: before or after button push.

Dipoles, cortical source sites of electrical activity, were identified using CURRY 7 software for the grand averaged ERP files (Compumedics Neuroscan, 2008; Näätänen, 2008). Dipole locations were determined from grand averaged ERP files. Locations of each dipole were compared between groups and the grand average for all deviant and standard responses within each block of stimuli. Brodmann areas were identified when possible for each condition and stimulus type. Although historically Brodmann areas were first differentiated based on cyto-architectual organization, many are correlated with diverse cortical functions. By aligning activation markers with Brodmann areas, increased detail of brain function is known. Information regarding brain function is not an exact science; however, the most accurate conclusions have been made in these results using current research regarding brain functions associated with activated areas from the Cortical Functions Reference Manual (Trans Cranial Technologies, 2012).

Each of the following figures contains four views: coronal, sagittal, axial, and MIP (maximum intensity projection). Colored areas signify the averaged regions of activation across participants during the presentation of the stimulus (standard or deviant). Below each of the four views is the mean global field power (MGFP) waveform which illustrates the brain's electrical activity by waveform at each time point in the field using data averaged from all participants. Stimuli were presented at the marker "0 ms" and the P300 response is marked on the waveform with the other listed time markers. Described below (see Figures 1-10) are the cortical areas activated during the various conditions. The MGFP exists as a point of reference for the cortical activation diagrams but the latency and amplitude of the waveforms will not be discussed.
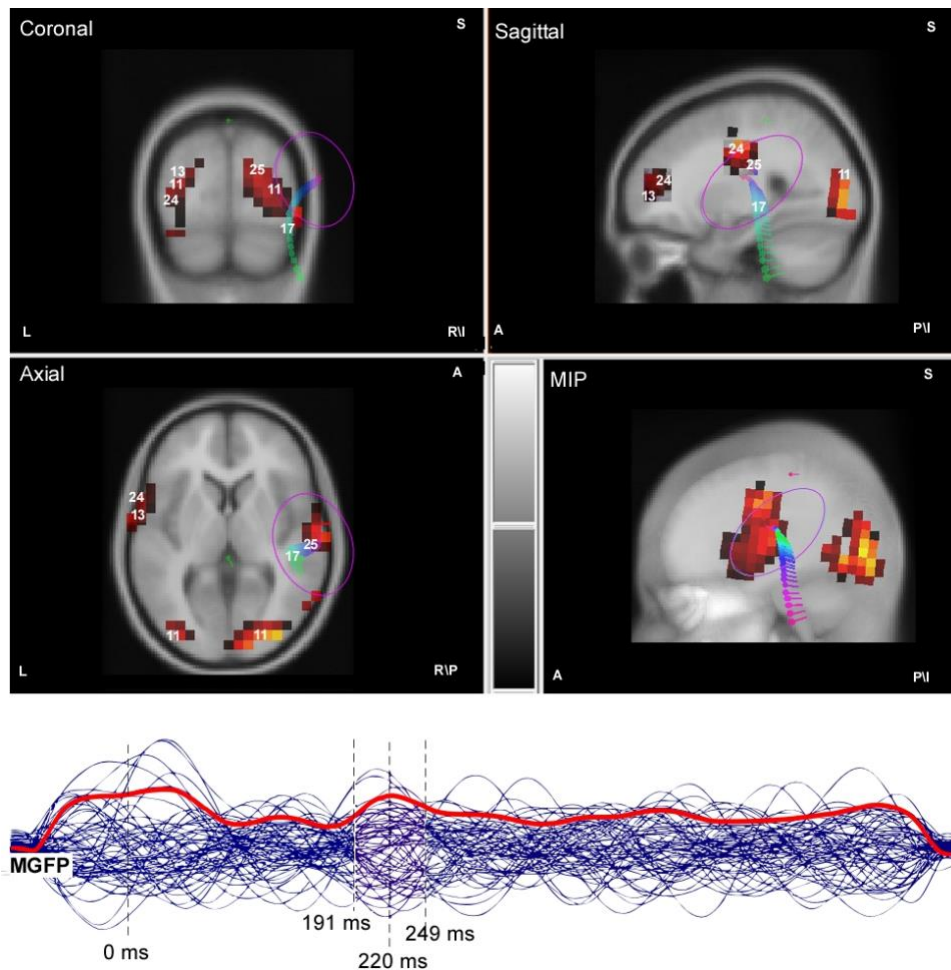
Figure 1. Brain activation response when standard stimuli presented during required motor response to deviant stimuli.

The middle occipital gyrus (11) is active on both hemispheres and fulfills primarily visual functions. There is activity in the left superior temporal gyrus (13) and BA 22 (24). These areas are primarily active for the processing of auditory information and are part of the primary auditory cortex. Activity is also seen in the right gyrus postcentralis (25), which is located in the lateral parietal lobe. This is the primary somatosensory cortex. There is also activity in the right parahippocampus (17), which reflects learning and memory function.
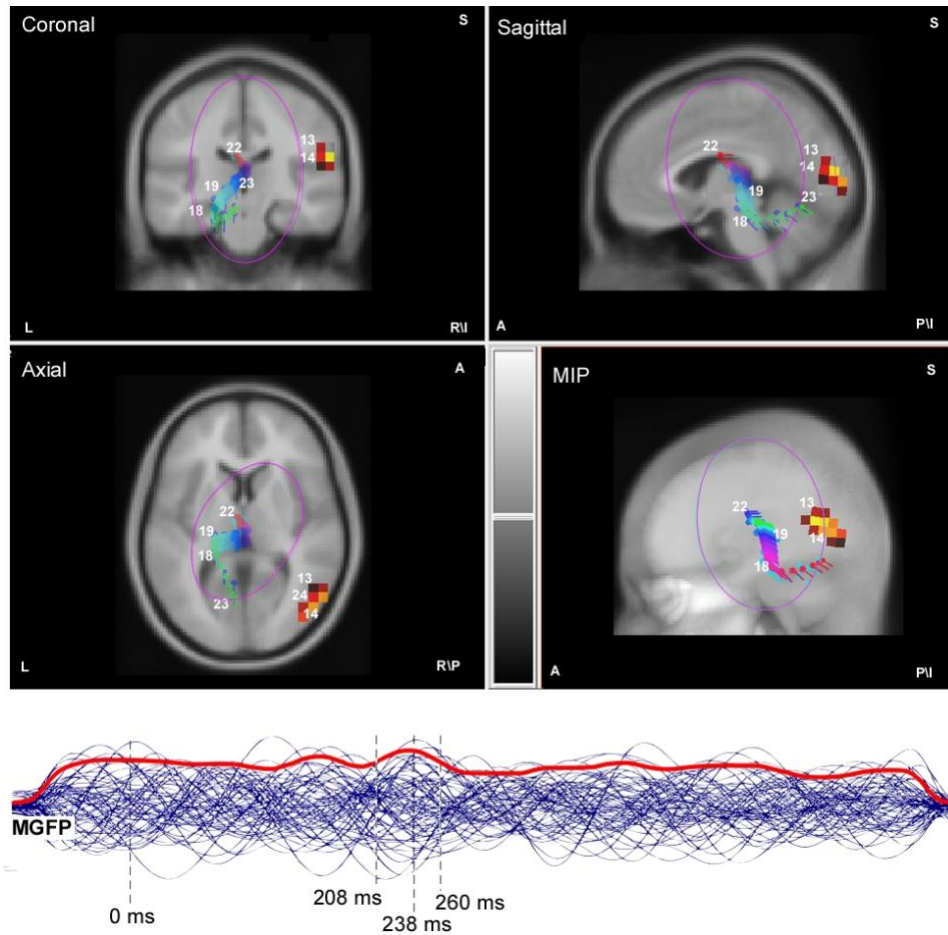
Figure 2. Brain activation response recorded when deviant stimuli presented during required motor response to deviant stimuli.

The left hemisphere includes activations of the thalamus (19) and the hypothalamus (18). These regions contribute to lexical semantic processing, selective attention to speech, and control of self-determined finger movements. The right hemisphere shows activation in the superior temporal gyrus (13), part of Brodmann area 22, and the middle temporal gyrus (14). The superior temporal gyrus has associated functions of receptive language, typically in the left hemisphere. However, the right superior temporal gyrus also has language functions, including prosody comprehension and selective attention to speech.
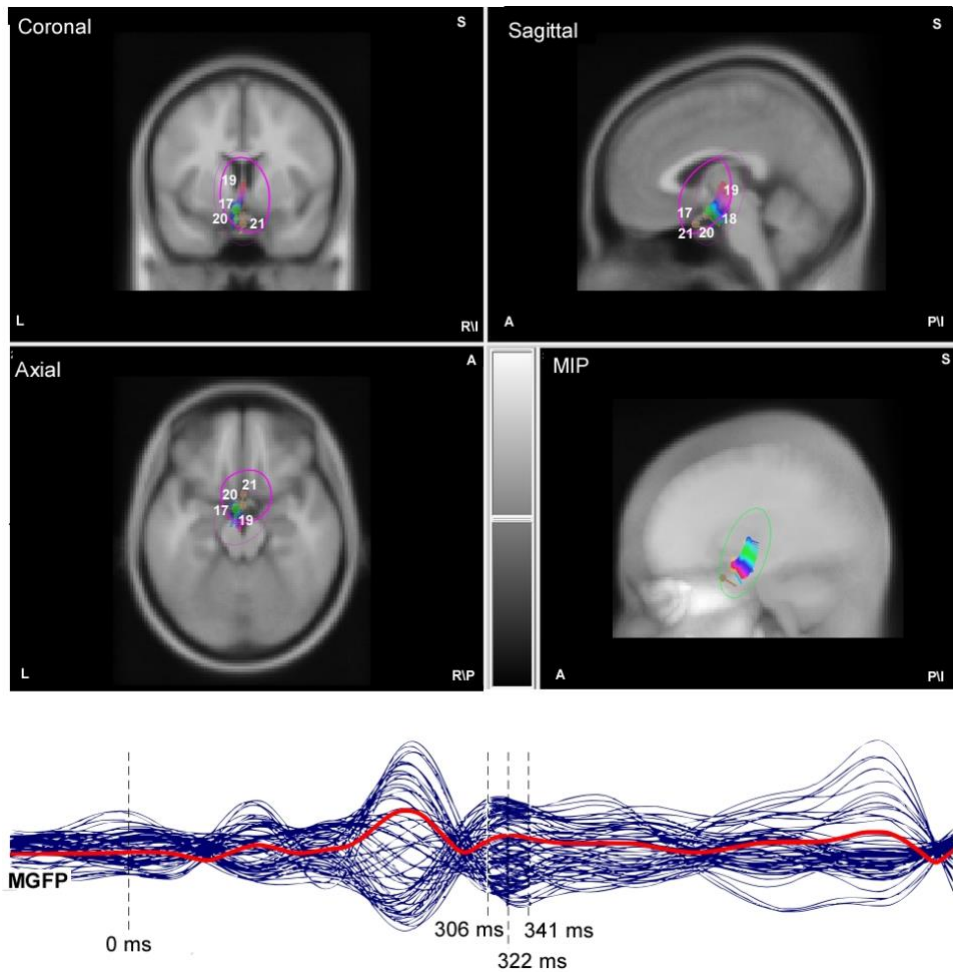
Figure 3. Brain activation response when standard stimuli presented during mental counting of deviant stimuli before completing motor response condition.

The primary areas of activation are in the left parahippocampus and left thalamus. The parahippocampus is part of the limbic system and processes complex learning and memory; especially, memory retrieval. The left thalamus is part of the posterior cingulate gyrus and includes functions of voluntary and involuntary recall and lexico-semantic processing.
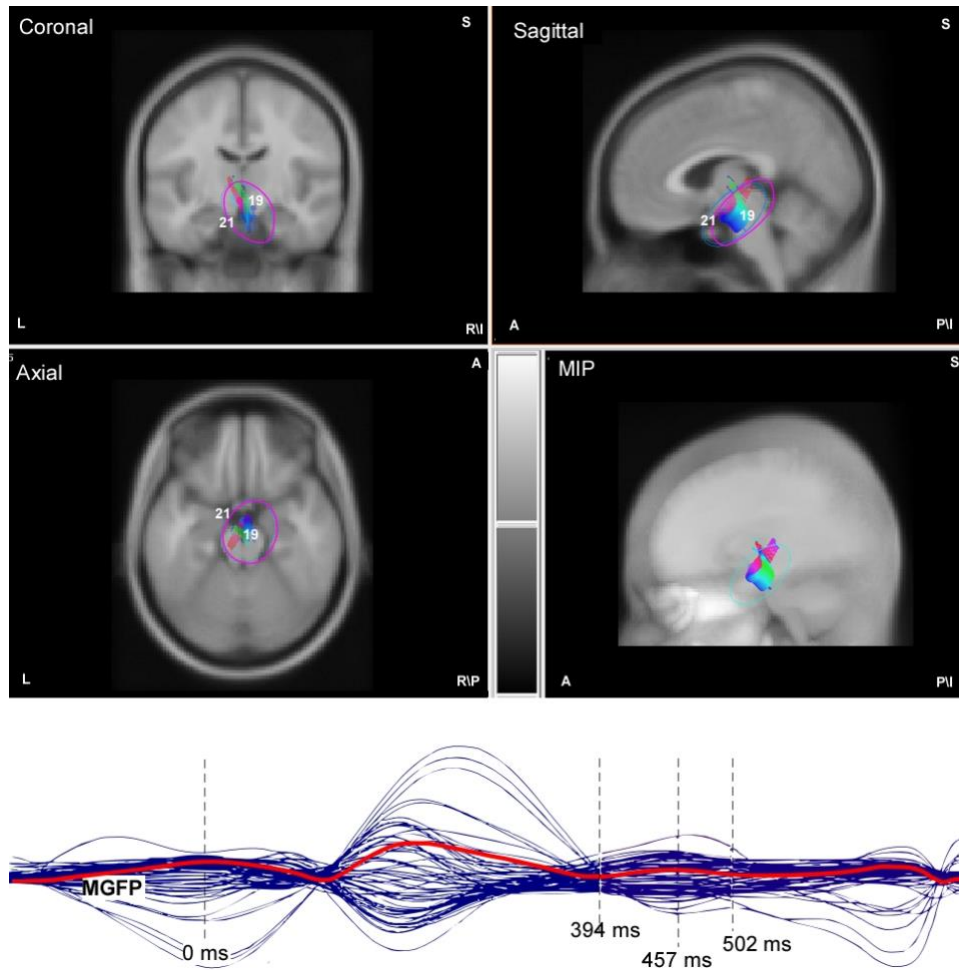
Figure 4. Brain activation response when standard stimuli presented during mental counting of deviant stimuli after completing motor response condition.

The active areas include the thalamus on both hemispheres; as well as Brodmann area 25 (21), which is involved in implicit moral reasoning and the evaluation of emotional words. As both thalamic regions show activation, functions may include response to classical conditioning, control of self-determined finger movements, evaluative judgment, and memory retrieval.
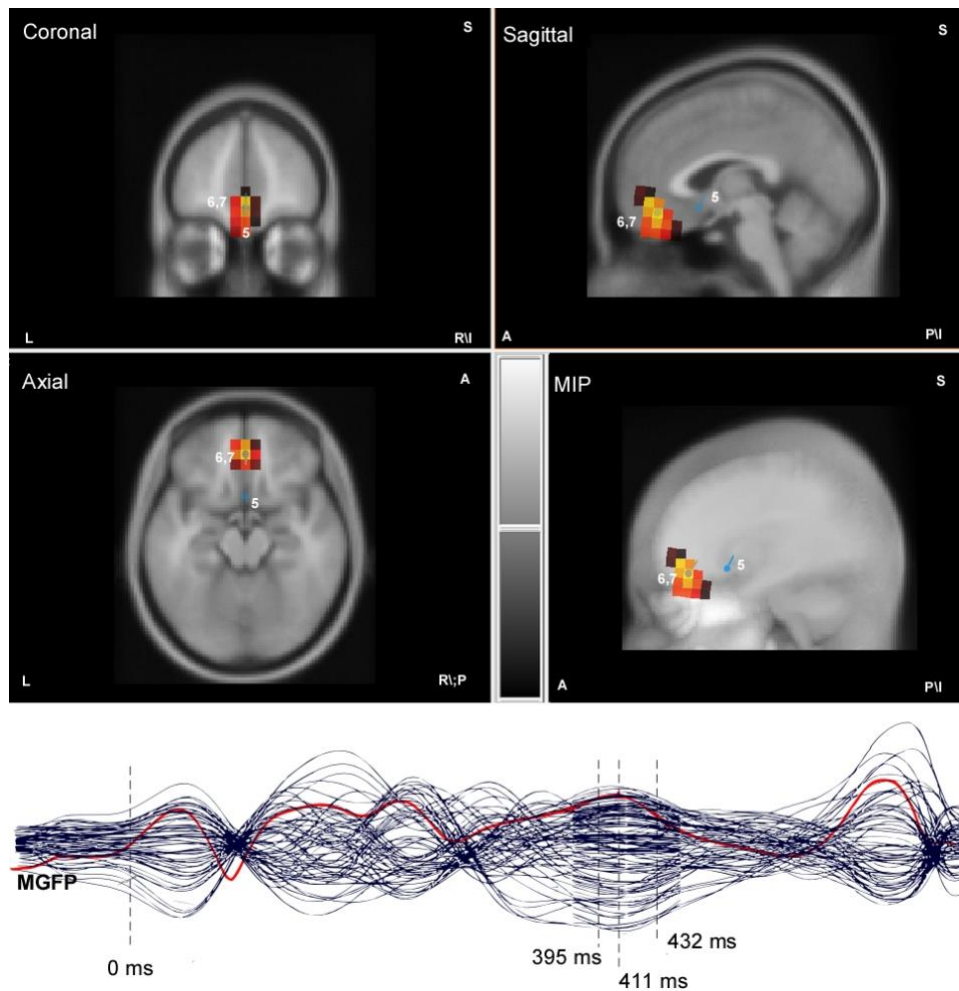
Figure 5. Brain activation response when deviant stimuli presented during mental counting of deviant stimuli before completing motor response condition.

Major activation is seen in the anterior cingulate cortex (5) and the middle frontal gyrus (6). The anterior cingulate cortex (5) is a major part of the limbic system and helps coordinate sensory input with emotion and conflict control (error detection). It consists of Brodmann area 24, responsible for emotion and mental timekeeping; Brodmann area 32 (7), related to decision processing; and Brodmann area 33, which is the association area for emotional processing. The middle frontal gyrus is located in the frontal lobe and is activated during working memory, control planning, and attention. Brodmann area 11 is also located in the region. During the mental counting trials, participants reported the number of deviant stimuli they heard. Out of the

correct 81 deviant stimuli, participants on average reported hearing 78 deviant stimuli throughout the 11-minute trial.
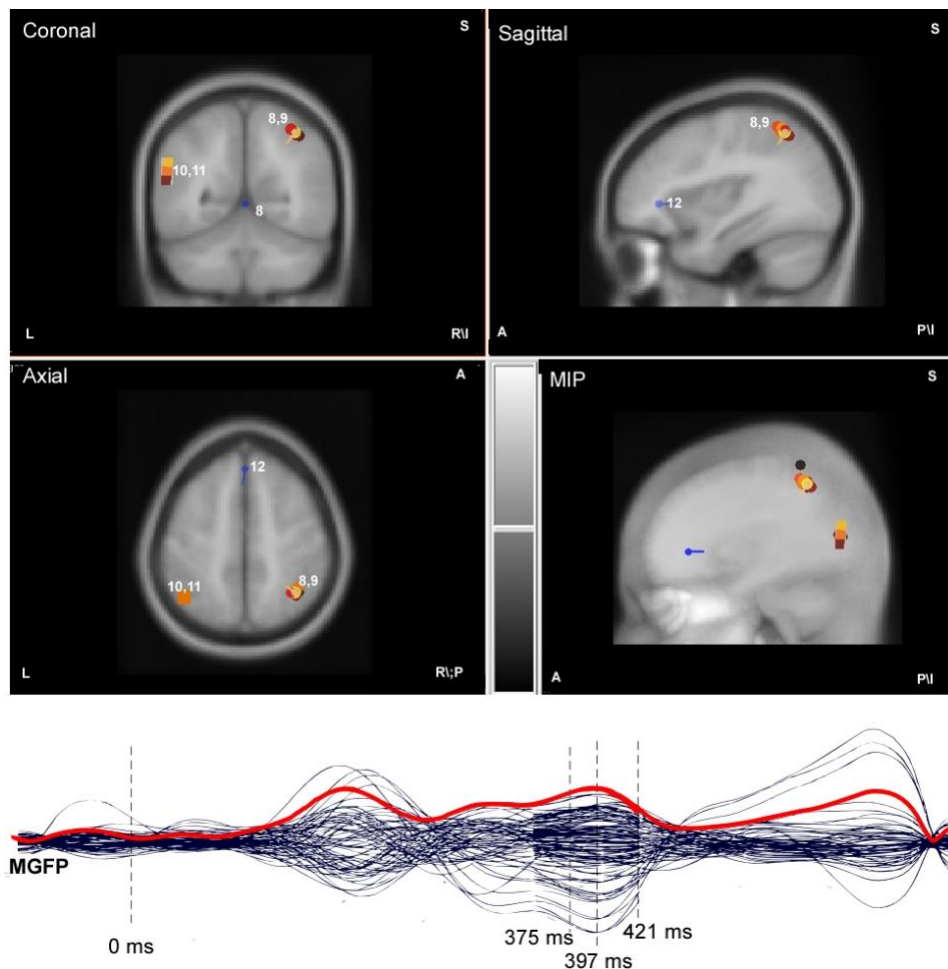

Figure 6. Brain activation response when deviant stimuli presented during mental counting of deviant stimuli after completing motor response condition.

The right inferior frontal gyrus (9) and the left middle occipital gyrus (11) are the primary areas of activation. The right inferior frontal gyrus (9) is also Brodmann area 44 (8) and is associated with go/no go tasks (e.g., button push) and is a measure of impulse control and risk aversion. Brodmann area 19 (10) is located in the middle occipital gyrus (11) and forms the major part of the striate visual cortex. One of its main functions is the perception of human body anatomy parts.   Brodmann area 11 (12) is located in the prefrontal cortex along with

Brodmann area 9 and Brodmann area 10. This area is primarily active in executive functions and cognitive control.
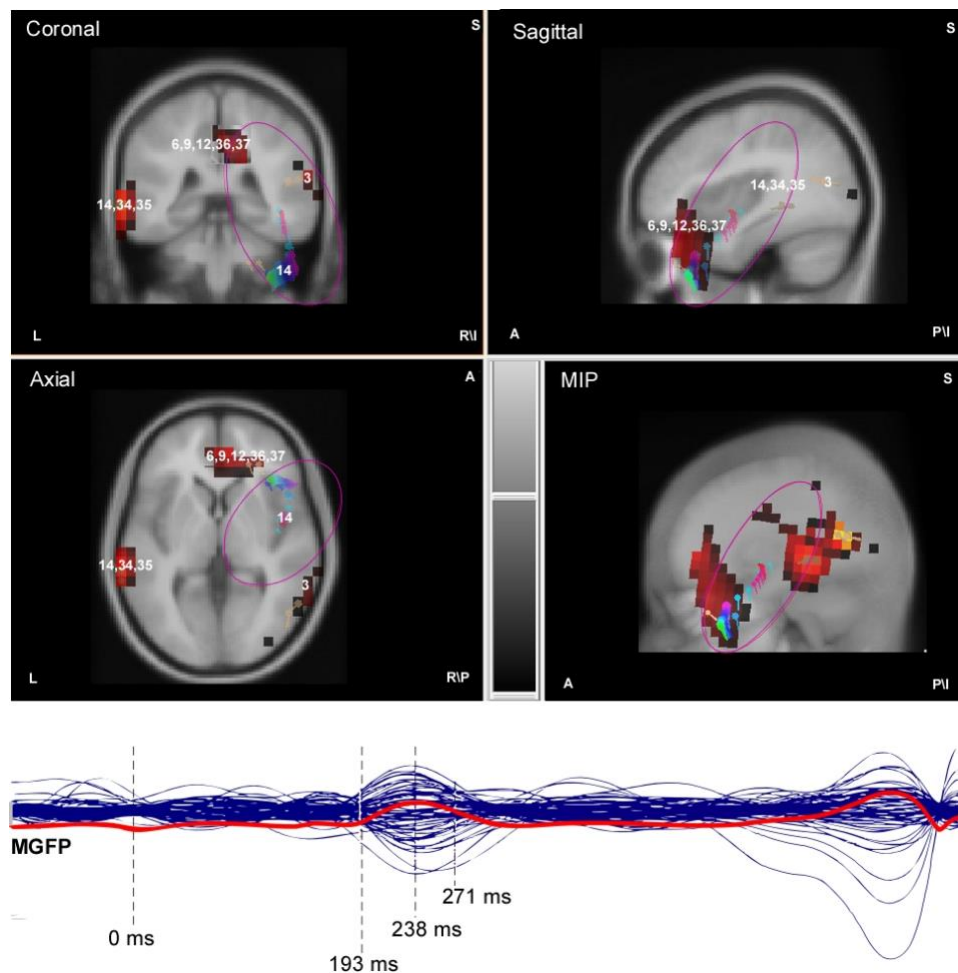
Figure 7. Brain activation response when standard stimuli presented during passive listening task completed before motor response condition.

The left temporal lobe shows activity in the middle temporal gyrus (14), Brodmann area 42 (34), and Brodmann area 21 (35). The middle temporal gyrus processes semantic memory, visual perception, integration of different sensory processes, specifically some types of mental imagery, and sequencing. The right superior temporal gyrus (3), which includes the primary auditory cortex, is active. This area is the first stage of perceptual decoding of auditory signals.
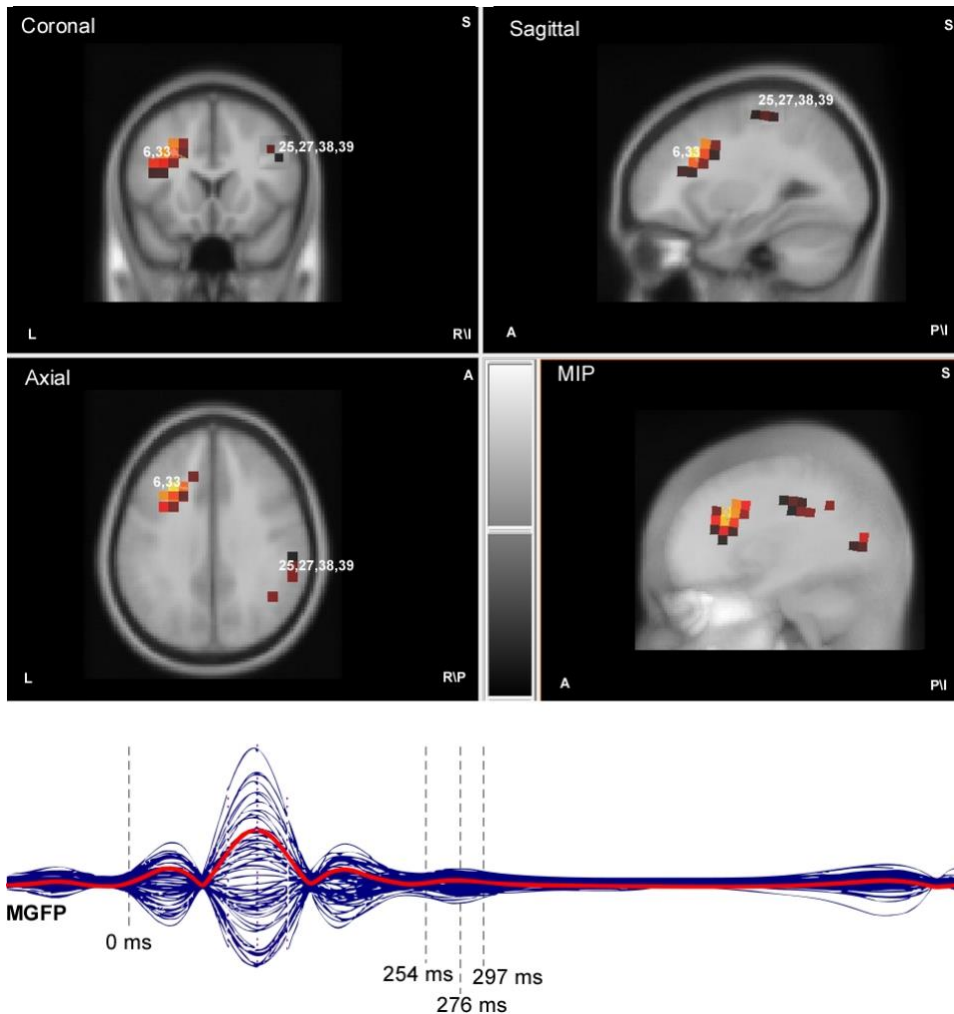
Figure 8. Brain activation response when standard stimuli presented during passive listening task completed after motor response condition.

Activation is seen in the inferior parietal lobe and supramarginal gyrus, which include Brodmann area 40 (27). These areas deal with functions of phonological relatedness and semantic processing. Also, Brodmann area 2 (38) and Brodmann area 3 (39) are part of the primary somatosensory cortex situated in the postcentral gyrus and include mirror neurons for speech perception, finger proprioception, and motor learning.

The superior temporal gyrus (3) and middle temporal gyrus (6) are active. The superior temporal gyrus functions to process sound identification and includes Wernicke's area. The middle temporal gyrus involves semantic memory and cognitive processing of language.
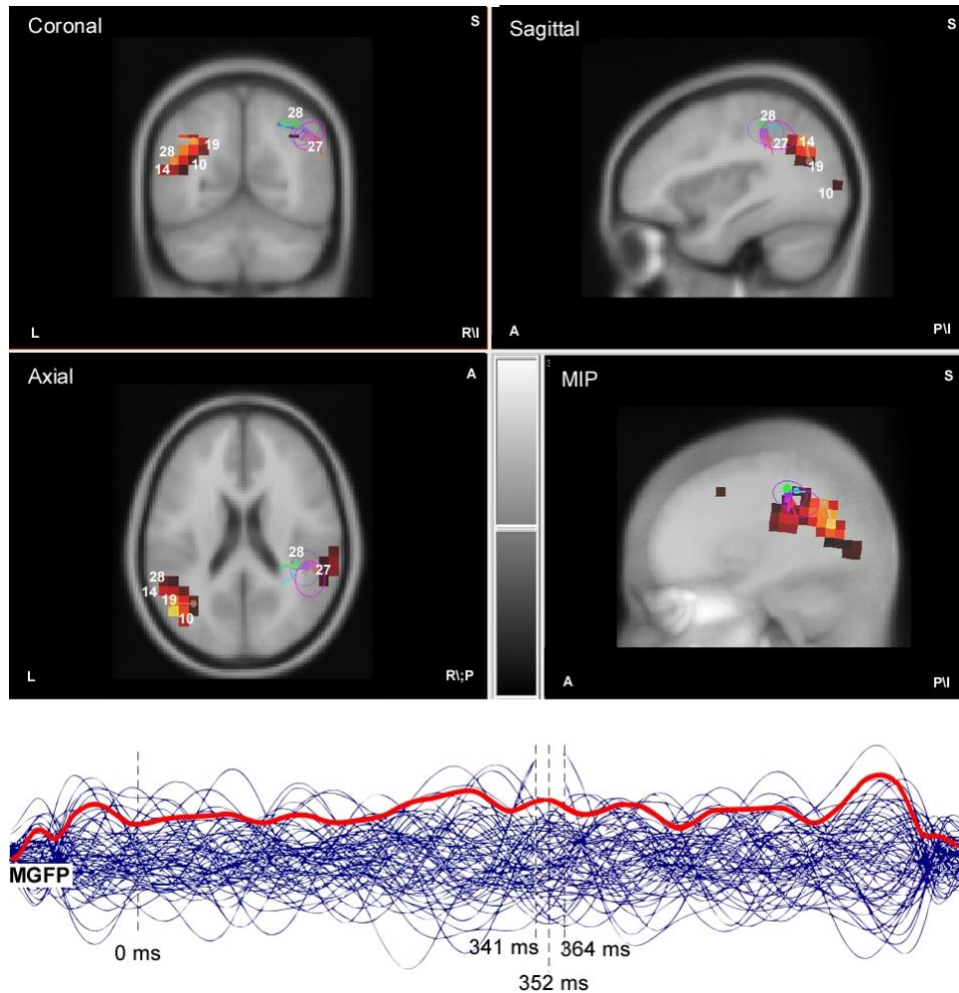
Figure 9. Brain activation response when deviant stimuli presented during passive listening task completed before motor response condition.

The majority of the activation is within the middle temporal gyrus (14) and includes Brodmann area 19 (10). These includes functions of speech processing, orientation-selective attention, and working memory. Brodmann area 40 (27) is active on the right hemisphere. This is typically active during somatosensory stimulation along with the supramarginal gyrus (28).
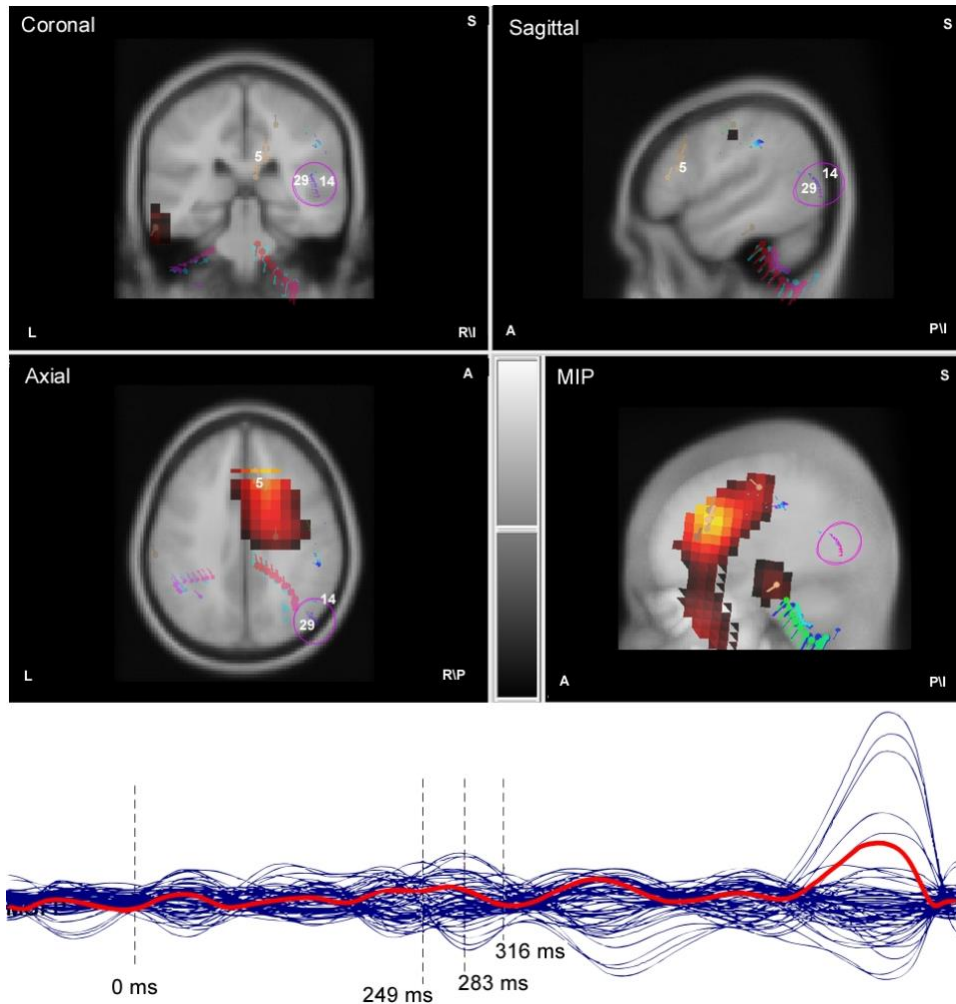
Figure 10. Brain activation response when deviant stimuli presented during passive listening task completed after motor response condition.

The middle temporal gyrus (14) is partly responsible for language and semantic memory processing. It is important in the retrieval of semantic tasks and information. Brodmann area 39 (29) is part of the angular gyrus and Wernicke's area. The right Brodmann area 29, which is the active region in this figure, is used in executive control of behavior (decision making). The anterior cingulate gyrus (5) is part of the limbic system and is involved in anticipation and pre-task preparation. It is also involved in error detection and conflict resolution.

Discussion

The purpose of the current study was to determine, using event-related potentials during phoneme discrimination tasks, if a motor response that is dependent on recognition of the deviant stimulus would influence speech perception during conditions of passive listening or mental counting completed directly after, and in comparison, to the condition requiring a motor response. Based on a review of the literature, it was hypothesized that similar areas of the brain would be activated in both the motor response task and the same task without a motor response immediately following the button-push condition.

Summary and Evaluation of Results

Motor response trial during presentation of deviant stimuli. Results from the current study reveal the various locations of cortical activation during phoneme discrimination with the influence of an additional cognitive load both before, during, and after. In conjunction with the expected outcome, the cortical areas activated during the motor response trial related to function of speech perception and motor activity during presentation of stimuli (Figures 1 and 2). During presentation of the standard stimuli, activated regions included gyrus postcentralis, the middle occipital gyrus, and the superior temporal gyrus. During presentation of the deviant stimuli, activated regions included the hypothalamus, middle temporal gyrus, superior temporal gyrus, and the thalamus. Ahmad, Balsamo, Sacha, Xu, and Gaillard (2003) identified the neural network associated with auditory comprehension as the left superior temporal gyrus, consistent with results of the current study. Of note, is the activation of the thalamus during the presentation of the deviant stimulus. A study done by Schubert, von Cramon, Niendorf, Pollman, and Bublak (1998) revealed the cortical areas involved in control of self-determined finger movements to include the thalamus in Brodmann area 23. The cortical activation from this portion of the study

are consistent with these findings. These two groups are compared to the other conditions during presentation of both standard and deviant stimuli.

Mental counting before and after required motor response trial during presentation of standard stimuli. Before the motor response trial, the primary areas of activation during this condition were areas correlated with memory retrieval, learning, and recall. After the motor response condition, the main area of activation during this task was seen in the thalamus, where functions include classical conditioning, control of self-determined finger movements, evaluative judgment, and memory retrieval. Although this task did not require the use of a motor response, results show activation in the cortical region associated with a motor response. This is indicative of carryover from the motor response trial to the mental counting trial done immediately after.

Mental counting before and after required motor response trial during presentation of deviant stimuli. Before the motor response condition, during the mental counting trial, the major areas activated were the anterior cingulate cortex and the middle frontal gyrus. After the motor response condition, the inferior frontal gyrus and the left middle occipital gyrus were the main areas activated. Function areas went from those related to mental timekeeping, error detection, working memory, and attention to including areas associated with go/no go tasks, impulse control, perception of human body anatomy parts, and risk aversion. The motor response trial, completed prior, required the participant to use all these functions. These differences illustrate, particularly the functions of perception of body, impulse control, and go/no go tasks, that the motor response trial done directly before the mental counting trial altered the way in which the brain was activated to attenuate more to the functions required of a motor response trial. A study done by Rizzolatti et al. (1996) localized active brain regions during observation and then participation of grasping objects. Results showed that during observation of grasping

movements, the superior temporal sulcus and left inferior frontal gyrus (Brodmann area 45) were active, indicative of mirror neurons for grasping movements being located in these areas (Rizzolatti et al., 1996). Similarly, in the current study, the left inferior frontal gyrus was active after the motor response trial had been completed during the mental counting. Although grasping movements were not used, fine motor control movement of the hand was used to press the button. The results of the current study indicate that cortical areas containing mirror neurons for hand movements were active during a task not requiring a motor response.

Passive listening before and after required motor response trial during presentation of standard stimuli. Cortical regions activated during both of these tasks had more similarities between the two conditions than those previously outlined. Both before and after the motor response, the superior temporal gyrus and middle temporal gyrus showed activation. These areas include the primary auditory cortex where the first stages of perceptual decoding occur. A study by Sekiyama et al. (2003) found activation in the primary auditory cortex during an audio-only condition, consistent with results from the current study. After the motor response condition, activation areas include those with functions of phonological relatedness, sound identification, and cognitive processing of language. Of note, is activation in Brodmann areas 2 and 3, where the primary somatosensory cortex resides and includes mirror neurons for speech perception, finger proprioception, and motor learning. This is evidence of carryover from the motor response condition as these functions relate to functions required during the motor response trial but not during passive listening.

Passive listening before and after required motor response trial during presentation of the deviant stimuli. The main difference seen in the brain's response after the motor response trial during the passive listening trial is the activation of the angular gyrus and the anterior

cingulate gyrus. These regions are associated with executive control (decision making) and anticipation and pre-task preparation. This leans to the conclusion that the participants were primed for the deviant stimulus over the course of the three trials due to these functions of anticipation and pre-task preparation. Whether the button push had more of an influence than simply hearing the stimuli repeatedly is plausible, but the result is not directly causal to the motor response trial due to insufficient evidence. In all three conditions during presentation of the deviant stimuli (passive listening before and after and motor response), the middle temporal gyrus showed activation, which is evidence that language and semantic memory processing was occurring.

Both before and after the motor response trial, during the passive listening trial, activation was seen in the right hemisphere in areas of Brodmann areas 29 and 40. Traditionally, speech processing has been attributed to the left hemisphere auditory cortex. Abrams et al., (2008) examined the involvement of the right hemisphere auditory cortex in coding slow temporal features of speech (3-5 Hz). Results revealed that the right hemisphere plays a specific role in acoustic speech processing (Abrams et al., 2008). Results from the current study were consistent with these findings based on the activation of right hemisphere cortical areas during passive listening phoneme discrimination tasks.

In a study done by Schmidt-Kassow et al. (2017), coupling a motor activity to auditory processing enhanced the efficiency of the processing. P300 amplitudes increased when motor and auditory components were synchronous. Schmidt-Kassow et al. (2017) used silent counting with an oddball paradigm to analyze participants' auditory processing both with and without motor movement that was not dependent on recognition of the deviant stimulus. Motor movement was found to improve phonemic encoding skills through an enhanced prediction

error. The current study required a motor response in recognition of the deviant stimulus during an oddball paradigm to determine if the location of phonemic encoding is altered in comparison to silent counting with no motor response. Based on the different cortical areas activated after the motor response trial during mental counting and passive listening tasks that relate to function of anticipation, body perception, evaluative judgment, control of self-determined finger movements, evaluative judgment, and memory retrieval, are suggestive of improved speech perception. However, more analysis of the ERP grand averaged waveforms is required to determine if a motor response that is dependent on recognition of the deviant stimulus would improve speech perception during conditions of passive listening or mental counting.

From a clinical perspective, coupling a motor response with speech production in patients with neurological damage has been shown to improve speech production. Bonakdarpour, Eftekharzadeh, and Ashayeri (2003) reported improvements in primarily spontaneous speech production following 15 sessions of melodic intonation therapy (MIT) in persons with chronic nonfluent aphasia. MIT employs the use of timed finger or hand tapping at the same time as each produced speech syllable. However, through use of a randomized controlled trial, Van Der Meulen, Van De Sandt-Koenderman, Heijenbrok, Visch-Brink, and Ribbers (2016) found that after six weeks of MIT, individuals with chronic nonfluent aphasia demonstrated improvement only in the repetition of both trained and untrained phrases. No generalization effects were seen to improve word retrieval or verbal communication in daily life. Van Der Meulen et al. used a small sample size, which may have created a bias in the results. Therapy that implements a motor response component to elicit speech in individuals with neurological damage does show improvement, albeit limited, in speech production. The current study aims to discover if a motor response improves or alters phonemic discrimination in the typical population. Previous

compelling research suggests that pairing a motor response with speech tasks may improve therapy outcomes for individuals with neurological damage. As a first step toward investigating this possibility, the current study aims to determine whether a motor response improves or alters phonemic discrimination in neurotypical adults.

In looking forward, speech perception tasks coupled with a motor response may possibly benefit those with fluent aphasias if motor responses are shown to benefit comprehension. Speech production and perception occur in different areas of the brain; however, as studies have shown improvement in speech production when coupled with a motor response, the improvement in one process may be similar to results in a different system due to the interconnectedness of the brain.

Limitations of the Study and Directions for Future Research

The study would be strengthened by a larger sample size and perhaps a greater diversity. Findings from the study would be more generalizable with a larger sample size. An additional limitation of the current study is the unknown influence of constraining variables, like participant boredom and fatigue, especially in tests with lengthy repeated measures. Results from the study depended on the participant's ability to maintain wakefulness and focus during the study. A signal detection paradigm with a receiver operating characteristic curve to measure button push response times would provide accuracy of phoneme discrimination correlated to qEEG data.

Also, individuals in this study may have experienced conditioning or priming during the repeated phoneme discrimination tasks that then potentially altered cortical activation. A study done by Laufer, Negishi, Lacadie, Papademetris, and Constable (2011) examined involvement of the middle frontal gyrus in response to an oddball paradigm experiment. The results of their study found that the right middle frontal gyrus had a less inhibited response to the target stimulus

during the oddball paradigm than the standard presentation. Laufer et al. concluded that there could be a competition model between the perceptual and conceptual effects in priming processing and that, depending on whether the stimulus was deviant or standard, the brain's response could become less inhibited. The order in which the conditions were presented to the participant may have biased the results from each condition. Memory of stimuli presentation during the mental counting condition may have influenced the results.

Typically, better spatial resolution is found using fMRI; however, the current study analyzed location of cortical activation using qEEG due to time and monetary constraints. Greater detail of changes in cortical activation regions may be found using fMRI. Using the same qEEG data from this study, future research may include analyzing latencies and amplitudes of the brain's response, along with the localization and dipole areas to provide information on timeliness in speech perception and amount of neural resources required for certain cognitive processes (Duncan et al., 2009).

No differentiation was made between male and female participants when reporting results. Future research may include comparison of male and female responses to report on differences in speech perception between sexes. The current study analyzed neurotypical individuals between the ages of 18 to 30. Future research may include similar tasks requiring additional cognitive and motor loads with neurologically damaged individuals of varying ages to see what benefit is found in comprehension of language, with regards to accuracy and timeliness. A study done by Engelien et al. (2000) took a participant with extensive bilateral destruction of the auditory cortices and examined the attentional modulation of localized brain regions and the sensory cortices when presented with auditory stimuli. Engelien et al. (2000) concluded that individuals with damaged sensory cortices may still have a conscious awareness of sounds, even

in the absence of the primary auditory cortex based on blood flow to the lateral prefrontal cortices, the middle temporal cortices, and the cerebellar hemispheres. This is evidence that in a damaged system, the brain exhibited neuroplasticity. Future research may include individuals with neurological damage to examine the neuroplasticity and carryover of brain activation during speech perception tasks.

Conclusion

This study examined the effects of a required motor response during a phoneme discrimination task and the influence of that response to the same task completed directly afterwards with no response required or mental counting of the deviant stimuli. By analyzing a receptive language task, information on location of brain activation during this task was acquired as well as the influence of, separately, an additional cognitive and motor load. Results showed that the required motor response directly before a mental counting condition and a passive listening condition altered what cortical regions were activated in response to both standard and deviant stimuli. These findings have potential benefit for patients with communication disorders, specifically those with receptive language deficits. It is important to consider the limitations of the study and directions for future research due to the introductory nature of the experiment on this subject.

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APPENDIX A

Informed Consent

Informed Consent to Act as a Human Research Subject
Mismatch Negativity Event-Related Potential Elicited by Speech Stimuli in Geriatric Patients
David L. McPherson, Ph.D.
Communication Science and Disorders
Brigham Young University
(801) 422-6458

Name of Participant: _____

Purpose of Study
The purpose of the study is to gain information in identifying changes in brain activity when older individuals hear different parts of speech.

Procedures
You have met the study criteria and have been asked to participate in this study by Dana Pierce, a student conducting research under the direction of David L. McPherson, Ph.D.

The study will be conducted in room 110 of the John Taylor Building on the campus of Brigham Young University. The testing will consist of one session including orientation. The testing will last for 2.5 hours. You may ask for a break at any time during testing. Basic hearing tests will be administered during the first half-hour of the session.

Surface electrodes (metal discs about the size of a dime) will be used to record the electrical activity of your brain. These discs will be applied to the surface of the skin with a liquid and are easily removed with water. Blunt needles will be used as a part of this study to help apply the electrode liquid. They will never be used to puncture the skin.

Acoustic and linguistic processing will be measured using an electrode cap, which simply measure the electrical activity of your brain and does not emit electricity; no electrical impulses will be applied to the brain. These measurements of the electrical activity are similar to what is known as an "EEG" or brain wave test. These measurements are of normal, continuous electrical activity in the brain.

You will wear the electrode cap while you listen to different speech sounds, during which time the electrical activity of your brain will be recorded on a computer. The sounds will be presented through insert earphones at a comfortable but not loud level. You will be seated comfortably in a sound treated testing room. You will be asked to give responses during the hearing test and portions of the electrophysiological recording by pressing a button.

The procedures used to record the electrophysiological responses of the brain are standardized and have been used without incident in many previous investigations. The combination of sounds presented is experimental, but the recording procedure is not.

Risks/Discomforts

There are very few potential risks from this procedure, and these risks are minimal. The risks of this study include possible allergic reactions to the liquid used in applying the electrodes. Allergic reactions to the liquid are extremely rare. There is also a possibility for an allergic reaction to the electrodes. If any of these reactions occur, a rash would appear. Treatment would including removing the electrodes and liquid and exposing the site to air, resulting in removal of the irritation. If there is an allergic reaction, testing procedures would be discontinued. Another unlikely risk is a small abrasion on the scalp when the blunt needle is used to place electrode gel. Treatment would also include removing the electrode and gel, exposing the site to air and testing procedures would be discontinued.

Benefits

You will receive a copy of your hearing assessment at no charge. You will be notified if any indications of hearing loss are found in this area. The information obtained may help to further the understanding of language processing, which will be beneficial to professionals involved in treating speech and hearing disorders.

Confidentiality

All information obtained from testing is confidential and is protected under the laws governing privacy. All identifying references will be removed and replaced by control numbers. Data collected in this study will be stored in a secured area accessible only to personnel associated with the study. Data will be reported in aggregate form without individual identifying information.

Compensation

You will be receiving $25.00 in cash for the session you attend for this study; you will receive cash whether or not you complete the study.

Participation

Participation in this research study is voluntary. You have the right to withdraw at any time or refuse to participate entirely without affecting your standing with the University. Also, participants of this study may be contacted in order to aid in an optional follow-up portion of this study.

Questions about the Research

If there are any further questions or concerns regarding this study, you may ask any of the investigators or contact David McPherson, Ph.D, Communication Science and Disorders, room 129, Taylor Building, Provo, Utah 94602; phone (801) 422-6458; e-mail: david_mcpherson@byu.edu.

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

Other Considerations
There are no charges incurred by you for participation in this study. There is no treatment or intervention involved in this study.

The procedures listed above have been explained to me by: _____
in a satisfactory manner and any questions relation to such risks have been answered.

I understand what is involved in participating in this research study. My questions have been answered and I have been offered a copy of this form for my records. I understand that I may withdraw from participating at any time. I agree to participate in this study.

Printed Name:_____

Signature:_____

Date:_____

APPENDIX B

Annotated Bibliography

Aerts, A., Strobbe, G., van Mierlo, P., Hartsuiker, R. J., Corthals, P., Santens, P., & De Letter, M. (2017). Spatiotemporal differentiation in auditory and motor regions during auditory phoneme discrimination. *Acta Neurol Belg, 117*(2), 477-491. doi:10.1007/s13760-017-0761-3

Objective: The purpose of this study was to further detail spatiotemporal differentiation in the fronto-temporo-parietal cortical network. The study compared passive and active auditory phoneme discrimination (APD) tasks based on place of articulation or voicing and manner of articulation. The authors hypothesized that place of articulation would elicit more motor cortical activity compared to voicing and manner of articulation eliciting more auditory cortical activity. *Study Sample:* Forty-seven participants (24 female and 23 male) took part in this study. All participants were right-handed. *Method:* Subjects were presented with stimuli consisting of /ba/ as the standard phoneme. Deviant phonemes were /ga/ for place of articulation difference, /pa/ for voicing difference, and /ma/ for manner of articulation difference. An auditory phoneme discrimination task was used in a pre-attentive, passive, and active condition. During the active listening condition, participants were instructed to press a button each time a deviant phoneme was heard. During the passive listening condition, participants were instructed to direct their attention to a silent movie. EEG was recorded for each participant using the international 10-20 system. SynAmp (Neuroscan) amplification was used to collect data. *Results:* Pre-attentive phoneme discrimination with manner of articulation as the phonemic contrast elicited more activation in sensorimotor, inferior parietal, and auditory superior temporal regions. Prior to MMN onset, the manner of articulation waveform corresponded to a peak, which may represent the need for higher activation of auditory regions with sensorimotor regions during phoneme discrimination. Manner of articulation required more auditory processing in comparison to place of articulation and voicing. During attentive phoneme discrimination tasks, spatial differentiation was first noted in motor areas, inferior parietal regions, and auditory superior temporal regions during voicing and manner of articulation phoneme discrimination. This pattern was then reversed with place of articulation tasks. *Conclusions:* Pre-attentive and attentive auditory APD tasks resulted in more auditory processing and auditory-to-motor mapping in early phases with manner of articulation. With place of articulation, there was delayed initiation of preparatory phases. With place of articulation as phonemic contrast, motor areas were used for attention-allocation and with manner and voice, auditory regions were used. *Relevance to current work:* This study provides evidence that when using place of articulation as phonemic contrast during auditory phoneme discrimination tasks, more motor cortical activity is observed during active listening tasks. The current study uses place of articulation as phonemic contrast to further examine spatiotemporal differentiation of motor cortical activity during active, passive, and motor-response trials. *Level of Evidence:* Level IIIa.

Alexander, J. E., Alexander, R. G., Crowson, B., Machan, K., Hall, C.A., Lockwood, D., & Godinez, D. (2005). Effects of self-evaluation on the P300 event-related potential. *Perceptual and Motor Sskills, 100*(2), 409-420.

Objective: The purpose of this study was to determine the effects of self-evaluation on P300 event-related potentials by contrasting three conditions: a standard ERP auditory oddball discrimination, a mental count of target tones during oddball discrimination, and an oddball task followed by participants' self-evaluation of surprise. *Study Sample:* Fifty-six undergraduate students (40 women and 16 men) participated in the study. *Method:* EEG was recorded using 15 electrodes during binaural presentation of 200 auditory stimuli tones. For each condition of the study, participants were instructed to press a specific key for the target tone with one forefinger and a different key for the standard tones with the other forefinger. In Condition 2, to keep track of participants' mental count, after the oddball phoneme, participants pressed the left response key if their count was odd or the right key if their count was even. During Condition 3, after participants responded to the target stimulus through button-press, they then pressed the right response key if they felt surprised by the tone or left if they felt they were not. Conditions 1, 2, 3 were presented to all participants in the same order. Results: P300 amplitudes were larger and latencies longer for Condition 3 with the target tones (oddball + self-evaluation). During Condition 2, no additional amplitude or latency differences were noted with the additional cognitive load in comparison to Condition 1. The greatest increase in activity was noted at the occipital and parietal locations during Condition 3 (self-evaluation). *Conclusions:* Based on the larger P300 amplitudes and longer latencies during Condition 3, self-evaluation may require more cortical resources than a sensory discrimination or cognitive exercise. As the self-evaluation/emotional response component primed participants for a certain stimulus, a greater amount of brain activity was noted to be required. *Relevance to current work:* The current study addresses phoneme differentiation tasks with an additional cognitive load of mental counting without an affective/self-evaluation component or button press. This study found that there was no noted difference in P300 levels between an ERP oddball task versus one with mental counting reported through button push. The current study will further examine if there are P300 differences between a baseline ERP oddball task with button push and a mental counting task without any motor response. *Level of evidence:* Level IIIa.

American Speech-Language-Hearing Association (1990). Guidelines for screening for hearing impairments and middle-ear disorders. *American Speech-Language-Hearing Association, 32*(2), 17-24. Retrieved from http://www.asha.org

Objective: The American Speech-Language-Hearing Association (ASHA) publishes specific guidelines regarding screening and assessing individuals for hearing impairments and disorders. These guidelines are set forth to safeguard against unethical practice in conducting hearing screenings. In addition, these guidelines ensure that results of hearing screenings are interrupted the same nationwide. *Relevance to current work:* Each participant in the current study had a hearing screening in order to be considered for additional QEEG investigation. The guidelines set forth by ASHA were followed in the participants' initial hearing screenings. *Level of evidence:* N/A.

Cacace, A. T., & McFarland, D. J. (2003). Spectral dynamics of electroencephalographic activity during auditory information processing. *Hearing Research, 176*(1-2), 25-41.

Objective: The purpose of this study was to measure if auditory information processing can alter the dynamics of ongoing EEG by synchronizing and/or desynchronizing EEG rhythms in various

frequency bands. Auditory event-related EEG rhythmicities were quantified using broadbrand spectral analysis. The oddball paradigm was used with changes in stimulus complexity, discriminability, and attention to specific events. *Study Sample:* Ten adults (four male and six female) participated in the study, ranging in age from 18 to 52 years old. *Method:* EEG was recorded from 24 electrodes. The oddball paradigm was used and participants were presented with eight conditions varying in stimulus complexity, stimulus discriminability, and attention. In the attend conditions, participants were instructed to press a button using their right index finger each time they discriminated the target stimulus from the standard stimuli. Reaction time measures were recorded in the attend condition. *Results:* Tone glides were more difficult to discriminate than pure tone stimuli (average JND for tone glides, 33.6 Hz, S.D., 8.4 Hz; average JND for pure tones, 13.5 Hz, S.D., 5.8 Hz). On conditions requiring a button-press, no noticeable difference was seen between stimulus type. In response to the target tone, increased P300 amplitudes were observed. Response amplitudes to the target averaged from each 600 ms epoch of individual trials showed a much greater amplitude enhancement in comparison to the standard stimulus, suggestive of intervening factors such as active discrimination and attention. With event-related synchronization, greater synchronization effects happened for more easily discriminable stimuli during oddball conditions. Event related desynchronization (ERD) effects were greatest in the attend condition with the oddball stimuli. Event-related beta band synchronization occurred for easily discriminable auditory stimuli in the attend condition. *Conclusions:* Auditory information processing can change ongoing EEG by synchronizing and/or desynchronizing EEG rhythms in varied frequency bands. *Relevance to current work:* In this study, increased P300 values were observed in response to the target stimulus, suggestive that the same result may occur in the current study. The current study will not use ERS/ERD to analyze data; however, it is valuable to understand alternative methods of data analyzation and results relating to the current study. *Level of evidence:* Level IIIa.

Csépe V. (1995). On the origin and development of the mismatch negativity. *Ear & Hearing, 16*(1), 91-104.

Objective: This article is a systematic review of findings on the generation, development, and diagnostic value of mismatch negativity (MMN). Discussed in the article were studies done to understand cortical and subcortical sources of the MMN, maturation of the MMN, and MMN as a tool to study impaired processes. Some of the experiments reviewed in the article were done by the authors of the article. *Conclusions:* Based on experiments done by the authors of this article, MMN is not elicited during sleep or anesthesia, which illustrates participants' need to be alert and awake for accurate data of MMN be collected. Stimulus novelty has no effect on MMN generation. The authors state that MMN is a feature-specific measure of ongoing sensory analysis and automatic discrimination of auditory stimuli, making it a valuable tool to study auditory dysfunction, maturation of acoustic discrimination, and assessment of individual perceptual abilities. However, little data is available on the maturation of MMN. In articles referenced in the review, MMN has been found in newborn babies and children. MMN in school-age children had the typical peak latency of the adult response. In a study done by the authors of this article, scalp distribution in children was different than adults. MMN was similar when elicited by pure tone and vowel deviants; however, with CV deviants, the distribution was more central and recorded over a larger area, showing a sensitivity to speech stimuli. Overall, the MMN develops early and may be a stable measure to test central auditory functioning. The

authors found that the MMN to speech stimuli with Wernicke's aphasia showed a late sustained negativity to stop consonants. This confirmed that lower level speech processing was preserved in these patients, which may or may not allow for access to higher level speech processing. Based on these results, impaired individuals' MMNs reveal a difference in brain processing. MMN can be used to measure auditory processing in newborn babies, young children, aphasia patients etc. The authors conclude that there is a need for reliable applications of MMN on normative data to allow for this measure to be used in cases when it is impossible to evaluate auditory-evoked potentials in other ways. *Relevance to current study:* This research showed that MMN is a reliable tool to measure auditory-evoked potentials if patients are alert. MMN can be used as a tool for typical participants within all age ranges. As the current study includes typical young adults and participants were instructed to stay alert, MMN will be a valuable diagnostic tool in analyzing results. *Level of evidence:* Level 1.

Csépe, V., Osman-Sági, J., Molnár, M., & Gósy, M. (2001). Impaired speech perception in aphasic patients: event-related potential and neuropsychological assessment. *Neuropsychologia, 39*(11), 1194-1208. doi: 10.1016/s0028-3932(01)00052-5

Objective: This study was done to evaluate whether the mismatch negativity (MMN) response to speech and non-speech auditory stimuli was deviant in individuals with aphasia. The study sought to determine if impairment was due to a phonemic processing deficit or related to phonetic features. In summary, aphasic individuals' processing of language was compared to typical processing. *Study Sample:* Four diagnosed aphasic patients and four neurologically unimpaired, control participants took part in this study. *Methods:* Three different types of stimuli were presented to participants: pure tones, front vowels, and consonant-vowel (CV) syllables. Event-related potentials were recorded for each individual via 21 electrodes using Neuroscan software while presented with auditory stimuli. *Results:* In all control subjects a reliable MMN was collected for all stimuli. The four aphasic participants all had MMN abnormalities. Specifically, the MMN elicited by pitch deviations was not significant enough to distinguish between the aphasic patients and the control group. The MMN elicited by consonant contrasts proved to show the most significant difference in aphasic patients in comparison with the control group. Lastly, a significant difference was seen in the MMN elicited by voicing and place of articulation for aphasic subjects. The MMN collected from the aphasic participants was either limitedly distributed, distorted, or completely missing. *Conclusions:* This study demonstrated that deficient processing of contrasting features were observed in those with damaged and/or disconnected regions of the language processing network (subjects with aphasia) when the MMN was elicited. MMN responses recorded from individuals with aphasia were clearly deviant compared to those with unimpaired neurological systems, demonstrating that neurological damage has an effect in brain processing. *Relevance to current work:* This research shows differences in brain processing in individuals with neurological impairment in comparison to typical subjects. These results support the current study's exclusion of individuals with known neurological, cognitive, or learning impairments as it would impact the accuracy of data collected. *Level of evidence:* Level IIIb.

Dehaene-Lambertz, G. (1997). Electrophysiological correlates of categorical phoneme perception in adults. *Neuroreport, 8*(4), 919-924.

Objective: The purpose of this study was to determine if phonetic deviants not present in the subjects' native language were phonemically processed in the same way as a phonetic deviant in the subject's native language using event-related potentials. *Study Sample:* Twelve right-handed native French-speaking subjects were included in the study. *Method:* Syllables were presented to subjects in a block of four syllables. The first three syllable were identical and the last was deviant. Subjects were presented with /ba/, dental /da/, and retroflex /Da/, which is a phoneme present in the Hindi language and generally indistinguishable to non-native Hindi speakers. Control trials (CO) consisted of four identical syllables. Within-category trials (WC) included a final syllable within the same phonetic category as the other four. Across-category trials (AC) included a final syllable that belonged to a different phonetic category. CO, WC, and AC trials were presented in both native and non-native phonemes. Subjects were instructed to signal if the last syllable was different through a yes/no response via button-push. Event-related potentials were collected using a 128 channel geodesic electrode net. The evoked response to the last syllable was reported. *Results:* In the AC native trials, French-speaking adults detected a syllable change 81% of the time. In all other categories, detection rates were low (below 20%). ANOVA was completed on detection rates with condition and phonetic contrast. All effects and interactions were significant. With the AC trial in the native language, there was a much greater evoked-response than in any other trial at around 200 ms. No MMN was observed near the non-native boundary. *Conclusions:* Both behaviorally and electrophysiologically, subjects indicated a greater sensitivity to an acoustic change from a phonemic boundary in their native language than in a non-native language. As a large MMN was observed for the AC trials in the native language, but was missing with the non-native language, and all acoustic differences between trials were identical, the author of the study hypothesized that phonemic characteristics are coded and stored in sensory memory. It is suggested that within sensory memory, there is a separate neural representation for a language-specific phonemic code. *Relevance to current work:* This study reported that phonemes are required to be within the subjects' native language in order for MMNs and ERPs to be significant. The current study employed phonemes within the English language and participants with English as their native language to accurately contrast MMNs and ERPs from passive and active listening tasks and motor-response tasks. *Level of Evidence:* Level IIIa.

Domahs, U., Kehrein, W., Knaus, J., Wiese, R., & Schlesewsky, M. (2009). Event-related potentials reflecting the processing of phonological constraint violations. *Language and Speech, 52*, 415-435.

Objective: The purpose of this study was to examine the effects of phonological constraints (existing words, well-formed novel words, and ill-formed novel words) on auditory processing through electrophysiological measures. *Study Sample:* Thirty-six right-handed native speakers of German (17 women, 19 men) participated in the study. *Method:* Participants were presented with each condition (word, pseudo-word and non-word) via loudspeakers. They were instructed to decide whether the target word was an existing German word within a sentence by pressing a button with their thumb to signal yes or no. EEG was recorded via 22 electrodes. *Results:* Both well-formed novel words and ill-formed novel words produced a negative deflection in comparison to grand averages of existing words. Non-words produced a positivity effect not seen with the other two stimuli types most pronounced in parietal regions. *Conclusions:* As both well-formed and ill-formed novel words produced an ERP effect on N400 compared to existing

words, novel words elicited a higher cost in lexical integration. Only ill-formed novel words produced a posterior positivity effect, demonstrating that violations of phonological constraints continue to influence later stages of cognitive processing, even after stimuli are detected as non-existing in the listener's language. *Relevance to current study:* The findings from this study illustrate that non-existing words influence cognitive processing. Due to such, in the current study, only existing phonemes in the English language were used as stimuli to minimize interference. *Level of Evidence:* Level IIIa.

, C. C., Barry, R. J., Connolly, J. F., Fischer, C., Michie, P. T., Näätänen, R., . . . Van Petten, C. (2009). Event-related potentials in clinical research: guidelines for eliciting, recording, and quantifying mismatch negativity, P300, and N400. *Clinical Neurophysiology, 120*(11), 1883-1908. doi:https://doi.org/10.1016/j.clinph.2009.07.045

Objective: The purpose of this document is to describe methods for the use of event-related brain potentials (ERPs) in clinical research to assist individuals who use ERPs in clinical research. The authors' goal is to help standardize methodology and comparability of data across laboratories. *Conclusions:* Mismatch negativity, P300, and N400 are each overviewed and described in terms of methodology and clinical applications. Of note for the current study, is the P300 ERP. It is also known as P3 or P3b. It is a large, broad, positive component ERP that peaks around 300 ms after the onset of a task-relevant stimulus. P3a may be elicited by a rare event that is not task-relevant and occurs around 250-300 ms and is a positive-going ERP component. P300 is typically elicited using an oddball paradigm. The lower the probability of an attended stimulus, the larger the amplitude of P300. Amplitudes are decreased when stimuli include successive repetitions. Target stimuli, which require a response, elicit larger P300 amplitudes. The more complex the stimulus processing of P300, the longer the latency. It is recorded from several cortical and subcortical locations. P300 is recorded using Fz, Cz, and Pz scalp locations. P300 is a slow potential, the authors recommend a high bandpass setting between 0.01 and 0.1 Hz. A low-pass setting of 100 Hz is recommended. Digitization rate of at least 200 Hz and a typical epoch of prestimulus 100-150 ms and 800-1000 ms post stimulus. P300 is measured as the peak amplitude and latency with a range. Area or mean amplitude within a selected interval may also be used. P300 is a sensitive measure of the capacity to allocate attentional resources. The authors review implications for P300 studies with a variety of adult and childhood disorders. *Relevance to current study:* The current study utilizes the P300 ERP to measure differences in response during a phoneme differentiation task. This research provides insightful information on the history, purpose, and use of P300 clinically. *Level of Evidence:* Level IIIa.

Grosvald, M., & Corina, D. (2012). Perception of long-distance coarticulation: an event-related potential and behavioral study. *Applied Psycholinguistics, 33*(1), 55-82. doi:http://dx.doi.org/10.1017/S0142716411000105

Objective: The aim of this study was to describe the functional organization of the human auditory cortex (AC) by comparing fMRI at rest and during active tasks and then to compare results to the current primate model of the AC. *Study Sample:* Nineteen participants (15 female and 4 male) were included in the study. *Method:* Participants were presented with iterated rippled noise bursts in three pitch categories (low, medium, and high). Stimuli were presented in twenty second task blocks with twelve second breaks where subjects focused on a fixation cross.

During pitch discrimination tasks, participants pressed a button with their right index finger when the second part of a sound pair was higher or lower than the first. Participants also completed pitch category tasks in which they decided if pitch tones were the same or different as the tone presented immediately prior. Data was collected using a 3 T MAGNETOM Skyra scanner, including both structural and functional images. *Results:* Activation was recorded in the anterior and posterior superior temporal gyrus, insula and inferior parietal lobule. Activation in the superior temporal gyrus was stronger in pitch discrimination tasks than in pitch category tasks. Connectivity patterns were similar between auditory tasks and between rest and visual tasks. When sounds were presented during visual tasks, increased connectivity was observed between the inferior parietal lobule and other modules. A modular network of six modules in the insula, superior temporal gyrus, and inferior parietal lobe in both lobes was identified. *Conclusions:* Based on the results of this study, a functional organization of human AC could be described. Functional connectivity patterns were regulated when sounds were presented during a visual task. There were differences noted between auditory and visual tasks, seen mainly in the inferior parietal lobule, suggestive of the inferior parietal lobe playing an important role in processing task-relevant and irrelevant auditory information. Overall, the functional connectivity patterns were similar during rest and active task conditions. Results show that functional connectivity in the region of the superior temporal gyrus and the inferior parietal lobe is dynamically modulated when sounds are presented in the absence of directed auditory attenuation and during active listening. *Relevance to current work:* In this study, functional connectivity was found to be similar in both auditory attenuation and active listening tasks using fMRI. The current study will analyze these conditions using QEEG. *Level of Evidence:* Level IIIb.

Hickok, G., & Poeppel, D. (2007). The cortical organization of speech processing. *Nature Reviews Neuroscience, 8*(5), 393-402. doi:10.1038/nrn2113

Objective: The purpose of this study was to define gender differences in the MMN using amplitude, latency, and topography of tonal and phonetic MMN. *Study Sample:* Eighteen right-handed males and ten age-matched females were included in the study. Methods: MMN responses to duration change of pure tone and phonetic change were recorded using auditory evoked potentials. Participants were presented with auditory stimulus sequences consisting of random standard and deviant stimuli. Each deviant stimulus was preceded by at least one standard stimulus. Participants were instructed to watch a silent film during the experiment while donning a 128-electrode cap. The experiment analyzed the MMN in response to a duration change of pure-tone stimuli and to an across-category vowel change. MMNs were measured by subtracting ERPS of standard stimuli from those of deviant stimuli. *Results:* No significant differences in latency, amplitude, or laterality for tonal or phonetic MMN were seen between male and female subjects. The mean global field power peak latencies of the male and female groups were 162 ms for the pure-tone MMN and 156 and 170 ms for the phonetic MMN. These results indicated that there is no significant effect of gender on either pure-tone or phonetic MMN amplitude. The MMN topography also indicated that there were no differences between genders but there were differences between conditions. The latency of the MMN also did not show a difference between genders but showed a difference between conditions. The latencies of the pure-tone MMN were significantly longer compared to the phonetic MMN, but this was found in both genders. *Conclusions:* For those studying MMN in healthy individuals, based on

the results of this study, gender will not obscure data. *Relevance to current study:* As both male and female participants were included in the current study, there will be no effect on the accuracy of the data collected. *Level of evidence:* Level IIIa.

Kasai, K., Nakagome, K., Iwanami, A., Fukuda, M., Itoh, K., Koshida, I., & Kato, N. (2002). No effect of gender on tonal and phonetic mismatch negativity in normal adults assessed by a high-resolution EEG recording. *Cognitive Brain Research, 13*(3), 305-312. doi: 10.1016/s0926-6410(01)00125-2

Objective: The purpose of this study was to clarify the role of gender differences in auditory MMN by comparing the amplitude, latency, and topography of tonal and phonetic MMN. *Study Sample:* Eighteen male participants and ten female participants, all of whom were native Japanese speakers, were included in the study. *Methods:* The MMN was measured using auditory ERPs. Participants were presented with auditory stimulus sequences consisting of randomly delivered standard and deviant stimuli; however, each deviant stimulus was preceded by at least one standard stimulus. The subjects were instructed to watch a silent film and were encouraged to ignore the stimuli. After the film, the subjects were required to report on the content of the film to further ensure their attention on the film. In addition, they reported on the characteristics of the stimulus sequence to determine if they behaviorally perceived the duration of tones and the phoneme boundaries. The experiment looked at two conditions: MMN in response to a duration change of pure-tone stimuli and MMN in response to an across-category vowel change. A 128-electrode cap was used to record the EEG. The ERPs of standard stimuli were subtracted from those of deviant stimuli to measure the difference waveforms of the MMNs. *Results:* The mean global field power peak latencies of the male and female groups were 162 ms for the pure-tone MMN and 156 and 170 ms for the phonetic MMN. These results indicated that there is no significant effect of gender on either pure-tone or phonetic MMN amplitude. Also, no difference was seen between genders with MMN topography and latency; however, latencies of the pure tone were significantly longer compared to the phonetic MMN in both genders. Following completion of participation, all subjects reported the content of the film and the information about the stimuli heard during the film accurately. *Conclusions:* Based on results from this study, gender has no effect on the amplitude, latency, or topography of tonal or phonetic MMN in normal adults using EEG. Based on these conclusions, researchers may combine male and female participants in further research using EEG and MMN with no adverse effects on results. The study also concluded that the pure-tone MMN was generated from Heschl's gyrus, and the phonetic MMN was generated from the planum temporalis. *Relevance to current work:* This study observed no gender difference in MMN data. As the current study includes both male and female participants, gender would not affect the collection of accuracy of the data. The current study will further provide evidence for location of MMN generation with phonetic stimuli. Level of evidence: Level IIIa.

Lin, E., & Polich, J. (1999). P300 habituation patterns: individual differences from ultradian rhythms. *Perceptual and Motor Skills, 88*(3 Pt 2), 1111-1125.

Objective: The purpose of this study was to determine the relationship between P300 amplitude and latency variability and ultradian EEG variation. Ultradian rhythms are biological rhythms that occur in approximately ninety minute cycles. *Study Sample:* Twenty-four students (12 male,

12 female) participated in the study. *Method:* Participants were presented with binaural tones in a random series with standard and target tones. Half the participants of each sex used the right thumb to press a button to indicate a standard stimulus and the left to indicate the target stimulus. The other half used the opposite hand-button combination. Event-related potentials were recorded using EEG electrodes. Ten trial blocks were presented, each lasting six to eight minutes with ten minutes between the onset of a trial block to the onset of the next trial block. *Results:* Behavioral data was stable across all subjects and trial blocks. After Blocks 1 and 2, all subjects exhibited an overall decrease in P300 amplitude, indicative of habituation to the target stimulus. Systematic variation for P300 latency over trial blocks for each subject group was approximately one standard deviation. *Conclusions:* Due to P300 latency variability, several successive ERP averages should be recorded to stabilize P300 amplitudes. P300 latency from repeated trial blocks may be averaged to increase precision of P300 measures. Results of this study supporting the hypothesis that ultraradian EEG variation is associated with P300 amplitude and latency variability are correlational. These results do not provide evidence for a causal relationship between P300 amplitude and latency and ultraradian EEG variation. *Relevance to current work:* Although ultraradian rhythms were not addressed in the current study, participants were presented with stimuli in three blocks, each lasting 11 minutes. The participants in this study exhibited habituation to the target stimulus via a decrease in the P300 amplitude over the course of twenty minutes. In analyzing data of the current study, as participants were presented with stimuli for over thirty minutes, habituation to the stimulus may be a confounding variable to consider. *Level of Evidence:* Level IIIa.

Schmidt-Kassow, M., Thöne, K., & Kaiser, J. (2017). Auditory-motor coupling affects phonetic encoding. *Brain Research.* In press. doi:https://doi.org/10.1016/j.brainres.2017.11.022

Objective: The purpose of this study was to determine if acute auditory-motor coupling facilitates phonetic encoding by measuring frequency presentation entrainment and event-related potentials. Previous studies have shown improved attention allocation and verbal learning occur when paired with synchronous movement. *Study Sample:* Twenty-four adults volunteered (11 female, 13 male) to participate in the study. All participants were undergraduates or doctoral students at the University of Frankfurt. Due to noisy data sets or technical problems, data from four participants was not included in the results. *Method:* Participants listened to synthesized syllables with an auditory oddball paradigm using syllables /pa/, /pla/, and /pfla/ and /pae/, /plae/, and /pflae/. For half of the subjects, syllables with the vowel /a/ were used as deviant and the other half used /ae/ as the deviant. Participants were instructed to silently count each deviant phoneme. Syllables were presented in three timing conditions: isochronous physical syllable onsets, isochronous vowel onsets, and jittered physical syllable onsets. Participants sat still on a stationary bike during half of the blocks and were instructed to pedal at a low intensity in the other half. EEG was recorded and digitized from 45 electrodes on a cap. *Results:* The P300 response revealed an enhanced prediction error. Coupling a motor activity to auditory processing enhanced the efficiency of the processing. P300 amplitudes increased when motor and auditory components were synchronous. *Conclusions:* This study provides evidence that auditory motor coupling performance improves auditory processing efficiency of phonetic stimuli. The results of this study indicate that linguistic processing may be enhanced through auditory-motor coupling. *Relevance to current study:* This study used silent counting with an oddball paradigm to analyze participants' auditory processing both with and without motor movement that was not dependent

on recognition of the oddball stimulus. Motor movement was found to improve phonemic encoding skills. The current study will employ a motor response in recognition of the deviant stimulus during an oddball paradigm to determine if phonemic encoding is improved in comparison to silent counting with no motor response. This study provides evidence towards the hypothesis that motor movement used to signal recognition of the deviant stimulus will improve phonemic processing. *Level of Evidence:* Level IIIa.

Sharma, A., & Dorman, M. F. (2000). Neurophysiologic correlates of cross-language phonetic perception. *The Journal of the Acoustical Society of America, 107*(5), 2697-2703. doi:10.1121/1.428655

Objective: The purpose of this study was to examine neurophysiologic correlates of the perception of native and nonnative phonetic categories through behavioral and electrophysiological responses. *Study Sample:* Ten native Hindi speakers and ten monolingual English speakers were included in the study. *Method:* Participants were presented with stimuli via headphones and asked to identify each stimulus as either /ba/ or /pa/ by clicking with a computer mouse on a corresponding button displayed on a computer screen. Following this task, participants were instructed to label two stimuli as "same" or "different" on the computer screen. Participants then were instructed to direct their attention to a movie with audio levels at 40 dB SPL or lower while test stimuli were presented through insert phones at 75 dB SPL in the right ear. Stimuli were presented using an oddball paradigm to elicit the MMN. The deviant stimulus was presented with a probability of occurrence of 15%. The -50 ms VOT stimulus was the deviant and the -10 ms VOT stimulus was the standard. Stimuli were presented at an offset-to-onset ISI of 510 ms. To elicit the N1, stimuli were presented at an onset-to-offset ISI of 800 ms. Electrophysiological data was collected using a NeuroScan data acquisition system. Auditory-evoked potentials were bandpass filtered on-line from 0.1 to 100 Hz. *Results:* Hindi listeners identified stimuli with voice onset times of 0 and -20 as /pa/ and -50 and -90 ms as /ba/. English speakers identified all stimuli as /ba/. With no prior training, monolingual speakers of English were unable to phonemically perceive pre-voicing. EEG data revealed a statistically significant MMN in Hindi-speaking listeners; however, a statistically significant MMN was not elicited in English listeners. N1 latencies, recorded from site Fz, systemically reflected the acoustic change from pre-voiced to voiced portion within the syllables equally well for both Hindi and English groups. *Conclusions:* The different responses recorded from MMN and N1 (with N1 present for both groups of participants and MMN only present for native Hindi speakers) reflect different levels of functional processing of the auditory-evoked potential. The N1 reflects stimulus processing which occurs at a sensory level not modified by exposure to phonetic categories of a language. The MMN results reveal that language specific categories contribute to this level of processing. *Relevant to current work:* The research done from this study reveals that the MMN is only elicited if stimuli presented are within phonetic categories known to the listener. The current study will use only native English speakers to eliminate any possible factors that may obscure the data. As well, the authors of this study outlined in detail the process of collecting and analyzing EEG data and waveforms, which will contribute to the collection and analyzation of data in the current study. *Level of evidence:* Level IIIa.

Tampas, J. W., Harkrider, A. W., & Hedrick, M. S. (2005). Neurophysiological indices of speech and nonspeech stimulus processing. *Journal of Speech, Language, and Hearing Research, 48*(5), 1147-1164. doi:10.1044/1092-4388(2005/081)

Objective: The purpose of this study was two-fold: to observe whether the MMN response is influenced by the phonetic characteristics of a stimulus or if it displays only an acoustic level of processing and to further expand knowledge on the neurophysiology of categorical perception, which is necessary for speech processing. *Study Sample:* Eight female and two male subjects participated in the study. All demonstrated normal hearing, were native English speakers, and reported no known neurological, cognitive, or learning deficits. *Method:* The CVs were 2 within-category stimuli and the non-speech stimuli were 2 glides whose frequency ramps matched the formant transitions of the CV stimuli. Only participants who were able to discriminate /ba/ and /da/ in a screening computer task were included in the study. Subjects completed discrimination tasks in which they indicated whether two stimuli were "same" or "different" by pressing a button prior to electrophysiological testing. Behavioral responses were collected during an oddball discrimination task in which participants listened to a speech and non-speech stimuli and were instructed to press a button when hearing the deviant stimulus. Two ERPs were measured, P300 and MMN, alternately during presentation of stimuli using an oddball paradigm. For MMN, individual mean waveforms and group grand mean waveforms were analyzed. *Results:* In the same/different discrimination tasks, stimulus type was found to be significant. In the oddball discrimination task, stimulus type was significant. Participants were more successful at discriminating between the non-speech versus the speech stimuli. The MMN response window was 80 to 400 ms. MMN was present only in the deviant and difference waveforms. The P300 response window was 200 to 500 ms. Again, it was only evident in the deviant and difference waveforms. No differences were found between ipsilateral and contralateral waveforms; therefore, all MMN and P300 analyses were performed on ipsilateral measures. An MMN response was elicited by the frequency glide stimuli and was absent in response to the speech stimuli. A clearly identifiable P300 waveform was present in response to the non-speech stimuli in the deviant and difference waveforms. The duration was from 270 to 310 ms. In response to the speech stimuli, the P300 waveform was smaller in amplitude and longer in latency. The duration was from 358 to 420 ms. In the P300 waveforms, greater amplitude to the glides versus CV stimuli was observed and peak latency was earlier when evoked by frequency glides versus speech stimuli. *Conclusions:* The speech and non-speech stimuli were processed differently when measured behaviorally, with MMN, or P300. More accurate discrimination and clearer neurophysiological representation of the non-speech stimuli versus the speech stimuli supports categorical perception representation at the level of the MMN generators and parallel processing of acoustic and phonetic information at the level of the MMN generators. *Relevance to current work:* The research done in this study played an important role in the current study because it asserts, through ERP analysis, that phonetic stimuli are processed differently than other acoustic stimuli. Results show categorical perception representation as early as the level of the MMN generators. *Level of Evidence:* Level IIIa.

Van Der Meulen, I., Van De Sandt-Koenderman, M. W. M. E., Heijenbrok, M. H., Visch-Brink, E., & Ribbers, G. M. (2016). Melodic intonation therapy in chronic aphasia: evidence from a pilot randomized controlled trial. *Frontiers in Human Neuroscience, 10*(533). doi:10.3389/fnhum.2016.00533

Objective: The purpose of this study was to determine the effectiveness of Melodic Intonation Therapy (MIT) in a randomized controlled trial on patients with chronic aphasia. *Study Sample:* Seventeen participants were recruited through the Dutch National Association of Persons with Aphasia and from outpatient aphasia center in the Netherlands. All participants were right-handed prior to stroke, >1 year post stroke, candidates for MIT, age 18-80 years, and a native Dutch speaker. *Methods:* The experiment consisted of two groups: control and therapy. The baseline characteristics of each group had no significant differences. The control group (7 participants) received no individual MIT treatment. Participants were permitted to continue participation in aphasia groups and low intensity group therapy to supplement verbal and non-verbal communication. The therapy group (10 participants) participated in MIT at levels of increasing difficulty according to the American MIT manual for six weeks. Therapy was given by experienced SLPs for five hours a week, starting with short, formulaic phrases with tapping on each syllable. Progressively, the final step involved independent spoken production of the target utterance. Assessment was done at baseline (T1), 6 weeks later (T2), and 12 weeks later (T3). *Results:* After six weeks of MIT, the therapy group displayed significant improvement on the repetition of both trained and untrained phrases but no improvement on other outcome measures. No generalization effects were seen to untrained material, word retrieval, or verbal communication in daily life. This study found no effect of MIT on auditory verbal comprehension. Treatment intensity was the only variable significantly relate to improvement after MIT. *Conclusions:* The results of this study suggest that effect of MIT in individuals with chronic severe non-fluent aphasia is limited. However, this study employed a small sample size and improvements were seen in subjects' ability to repeat trained and untrained phrases. *Relevance to current work:* This study reported on the improvement of speech production (in the form of repetition) after using therapy that implements a motor component to elicit speech in individuals with neurological damage and found that improvement, albeit limited, was evidenced. The current study aims to discover if a motor response improves or alters phonemic discrimination, a small component of speech comprehension, in any way. *Level of Evidence:* Level IIIb.

Weiss, S., & Mueller, H. M. (2003). The contribution of EEG coherence to the investigation of language. *Brain and Language, 85*(2), 325-343.

Objective: This paper is a selective review to organize and discuss the contributions of EEG coherence analysis on the study of cognition and language processing. *Conclusions:* An overview of language processing is provided outlining the need for both localized and distributed patterns of information transfer. Singer and Gray (1995) are referenced for the temporal correlation hypothesis, which states that neurons with similar feature properties can synchronize their discharges. EEG coherence is defined as a large-scale measure that depicts dynamic functional interactions between electrode signals. If high coherence is found at different sites, functional interplay may be involved between the underlying neuronal networks. Types of time series analysis are described. Spectral analysis is the most common form of EEG analysis; EEG signals are transformed from the time domain to the frequency domain using the Fourier transform. To answer for certain constraints, more sophisticated approaches were created for analysis, like the ARMA model, which has time varying parameters to monitor and quantify signal content of two recordings. Interpretation of coherence is outlined: high coherence between

two EEG signals during, for example, a language task but not at rest may mean high cooperation between the two areas and, therefore, neuronal synchronization. Phase relations are discussed as they are connected to coherence. The impact of event-related potential studies is described; ERPs do not give information on activity within frequency bands. Few studies on EEG coherence and language processing have been performed due to previously unavailable computer power. Clinical studies on dyslexia, the only studies on EEG coherence and specific language disorders done as of 2003, reveal that generally, a reduced coherence is found in dyslexic patients compared to their typical peers during language processing. Language processing in healthy adult studies were reviewed. Word perception elicits changes in patterns of coherence in both high and low frequencies. In summary, coherence is a measure of information flow between groups of neurons in varying locations and may be used to measure the relationship between EEG signal during cognitive function. High coherence is found with greater task complexity and efficient information processing; low coherence may be found in pathological conditions. Right hemispheric participation is found during processing of complex language stimuli. By measuring EEG coherence, language comprehension and production is correlated with interaction, not location. *Relevance to current study:* This review outlined a method to measure interactions between regions of the brain during language processing tasks. The current study is seeking to quantify ERP differences between active and passive listening tasks with and without the influence of a motor response. This review provides insight into future research that may be done following the current study involving different analysis methods and neurophysiological techniques to further understand the functional interplay of neuronal networks. *Level of Evidence:* Level IIIa.

World Medical Association (2013). *WMA declaration of Helsinki: Ethical principles for medical research involving human subjects*. World Medical Association, Inc. Retrieved from https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/

Objective: This document was created by the World Medical Association (WMA) as a statement of ethical principles that should be followed for medical research involving human subjects. The principles also should be followed in research involving identifiable human material and data. *Relevance to current work:* The current study was done in an ethical manner in harmony with the principles stated in the Declaration of Helsinki. Along with being in accordance with the Declaration of Helsinki, the current research was also conducted under the ethical principles upheld by Brigham Young University's Institutional Review Board (IRB). In addition, the current study was approved by the Brigham Young University IRB. *Level of evidence:* N/A.