Mismatch Negativity Event Related Potential Elicited by Speech Stimuli in Geriatric Patients

Dana Lynn Pierce
Brigham Young University

Follow this and additional works at: https://scholarsarchive.byu.edu/etd

BYU ScholarsArchive Citation

This Thesis is brought to you for free and open access by BYU ScholarsArchive. It has been accepted for inclusion in Theses and Dissertations by an authorized administrator of BYU ScholarsArchive. For more information, please contact scholarsarchive@byu.edu, ellen_amatangelo@byu.edu.
Mismatch Negativity Event Related Potential Elicited by
Speech Stimuli in Geriatric Patients

Dana Lynn Pierce

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

David L. McPherson, Chair
Shawn L. Nissen
Martin Fujiki

Department of Communication Disorders
Brigham Young University

Copyright © 2019 Dana Lynn Pierce
All Rights Reserved
ABSTRACT

Mismatch Negativity Event Related Potential Elicited by Speech Stimuli in Geriatric Patients

Dana Lynn Pierce
Department of Communication Disorders, BYU
Master of Science

Hearing loss, as a result of old age, has been linked to a decline in speech perception despite the use of additional listening devices. Even though the relationship between hearing loss and decreased speech perception has been well established, research in this area has often focused on the behavioral aspects of language and not on the functionality of the brain itself. In the present study, the mismatch negativity, an event related potential, was examined in order to determine the differences in speech perception between young adult participants, geriatric normal hearing participants, and geriatric hearing-impaired participants. It was hypothesized that a significantly weaker mismatch negativity would occur in the geriatric hearing-impaired participants when compared to the young adult participants and the geriatric normal hearing participants. A passive same/different discrimination task was administered to 10 young adult controls (5 male, 5 female) and eight older adult participants with and without hearing loss (4 male, 4 female). Data from behavioral responses and event related potentials were recorded from 64 electrodes placed across the scalp. Results demonstrated that the mismatch negativity occurred at various amplitudes across all participants tested; however, an increased latency in the presence of the mismatch negativity was noted for the geriatric normal hearing and the geriatric hearing-impaired participants. Dipoles reconstructed from temporal event related potential data were located in the cortical areas known to be instrumental in auditory and language processing for the young adult participants; however, within the geriatric normal hearing and the geriatric hearing-impaired participants, dipoles were seen in multiple locations not directly associated with language and auditory processing. Although not conclusive, it appears that within the geriatric normal hearing and the geriatric hearing-impaired participants there is slower processing of the speech information, as well as some cognitive confusion which leads to fewer available resources for interpretation.

Keywords: electroencephalography, event related potentials, mismatch negativity, brain mapping, geriatric, dipole localization
ACKNOWLEDGMENTS

I would like to thank my thesis chair, Dr. McPherson, for his trust and guidance throughout the course of this project. Additionally, I would like to thank my family and friends for providing constant encouragement and motivation. I would also like to thank my husband, Scott, for his unwavering love and support.
# TABLE OF CONTENTS

ABSTRACT ................................................................................................................................. ii

ACKNOWLEDGMENTS .................................................................................................................. iii

TABLE OF CONTENTS ................................................................................................................ iv

LIST OF TABLES .......................................................................................................................... vi

LIST OF FIGURES ....................................................................................................................... vii

DESCRIPTION OF THESIS STRUCTURE .................................................................................. viii

Introduction .................................................................................................................................. 1

  Auditory Processing .................................................................................................................... 2

  Speech Perception ..................................................................................................................... 2

  Quantitative Electroencephalography ...................................................................................... 3

  The Mismatch Negativity .......................................................................................................... 3

Statement of Purpose .................................................................................................................. 4

Method .......................................................................................................................................... 4

  Participants ................................................................................................................................. 4

  Stimuli ......................................................................................................................................... 5

Procedures ..................................................................................................................................... 6

  Initial screening .......................................................................................................................... 6

  EEG data collection .................................................................................................................. 6

  Data acquisition ........................................................................................................................ 6

Data Analysis ............................................................................................................................... 8

Results .......................................................................................................................................... 8

Discussion .................................................................................................................................... 19
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summary and Evaluation of Results</td>
<td>19</td>
</tr>
<tr>
<td>Young adult participants</td>
<td>19</td>
</tr>
<tr>
<td>Geriatric normal hearing participants</td>
<td>21</td>
</tr>
<tr>
<td>Geriatric hearing-impaired participants</td>
<td>23</td>
</tr>
<tr>
<td>Comparisons between participants</td>
<td>24</td>
</tr>
<tr>
<td>Limitations of the Study and Directions for Future Research</td>
<td>24</td>
</tr>
<tr>
<td>Conclusion</td>
<td>25</td>
</tr>
<tr>
<td>References</td>
<td>27</td>
</tr>
<tr>
<td>APPENDIX A: Informed Consent</td>
<td>31</td>
</tr>
<tr>
<td>APPENDIX B: Figure Key</td>
<td>34</td>
</tr>
<tr>
<td>APPENDIX C: Annotated Bibliography</td>
<td>36</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 1  Descriptive Statistics......................................................................................................................... 10
LIST OF FIGURES

Figure 1. Brain activation response in young adult participants................................. 11
Figure 2. Brain activation response in the geriatric normal hearing participants.................. 12
Figure 3. Brain activation response in the geriatric hearing-impaired participants.............. 13
Figure 4. Brain activation response in comparisons between participants.......................... 14
DESCRIPTION OF THESIS STRUCTURE

This thesis, *Mismatch Negativity Event Related Potential Elicited by Speech Stimuli in Geriatric Patients*, functions as part of a larger research project. The contents of this thesis may be published as part of articles listing the thesis author as a co-author. This thesis was written as a manuscript suitable for submission to a peer-reviewed journal in audiology and speech-language pathology. For additional information regarding the current research, Appendix A contains an informed consent document, Appendix B provides a key pertaining to cortical location labels in MMN figures, and Appendix C provides an annotated bibliography.
Introduction

Hearing loss, as a result of old age, has become increasingly prevalent. It has been estimated that, within the United States, 63.1% of individuals aged 70 years and older possess some degree of hearing loss (Lin, Thorpe, Gordon-Salant, & Ferrucci, 2011). Furthermore, a decline in speech perception, or the ability to comprehend meaning from auditory speech stimuli, is commonly associated with age-related hearing loss (Pichora-Fuller & Souza, 2003).

Speech perception is an important element of everyday life. Our daily interactions revolve around comprehending and understanding speech. However, difficulty with speech perception can lead to loneliness or withdrawal from society and is a major contributor to decreased quality of life in the aging population (Ciorba, Bianchini, Pelucchi, & Pastore, 2012; Dalton et al., 2003). With the prevalence of hearing loss in the geriatric population and other associated challenges, research regarding this area is becoming increasingly important.

Difficulty with speech perception is commonly attributed to a lack of amplification. Present treatment of speech perception deficits focuses on resolving issues pertaining to sound intensity (American Academy of Audiology Task Force, 2006). However, in the process of understanding auditory stimuli, the functionality of the hearing mechanism and the intensity of the signal received, play a relatively minor role. In fact, the major function of the inner, middle, and outer ear is to convey the appropriate auditory information to the brain. Once the brain receives the auditory information, speech perception can occur (Gelfand, 2006). Due to the necessity of the brain's involvement in speech perception assistive listening devices poorly compensate in noisy and fast-speech conditions (Na, Kim, Kim, Han, & Kim, 2017).

Much of the previous research regarding speech perception in the geriatric population has focused on the behavioral aspects of language and not on the functionality of the brain itself.
(Sommers, 1997). For this study, we sought to observe how speech perception is processed in the brain. Specifically, how the brain differs in its processing of speech information in a young adult population as compared to geriatric population with normal and impaired hearing. In order to do this, we utilized quantitative electroencephalography (qEEG), dipole source localization, and brain mapping to determine what occurs in the brain as speech perception occurs. Furthermore, the mismatch negativity (MMN) was observed in order to determine the brains ability to process speech stimuli.

**Auditory Processing**

Due to the abstract nature of speech processing, it is essential to first understand how sound is transmitted to the brain. When an auditory stimulus reaches the ear, the pressure from the transmitted sound waves cause the tympanic membrane to vibrate. The movement of the tympanic membrane then activates the ossicles. The ossicles, by means of the oval window, transmit the sound signal to the inner ear. Once the sound waves have been transmitted into the inner ear the movement activates the outer and inner hair cells within the cochlea. The movement of the hair cells results in the initiation of neural impulses. The neural impulses are transmitted by the auditory nerve to auditory and non auditory areas of the cerebral cortex, where the brain processes the auditory information into speech (Gelfand, 2006).

**Speech Perception**

Speech perception is essential to communication because all auditory stimuli needs to be processed and understood by the brain. In order for a sound to be comprehended, it must first go through a process whereby the brain assigns meaning to that sound. It is well known that the brain plays a highly involved role in the process of speech perception, however, relatively little is known about exactly how the brain converts sound energy into meaningful language (Lee, 2015).
Quantitative Electroencephalography

To examine the functionality of how the brain processes speech, the current study utilized qEEG, which has been shown to be a reliable resource in monitoring brain activity during speech perception (Cheour et al., 1998). Electrical signals sent by the brain via neurons are captured by placing electrodes on the surface of the scalp in qEEG. Through the use of digitization, qEEG provides accurate temporal data and estimated spatial data. In qEEG, changes in electrical signals as a function of variations in certain stimuli result in event related potentials (ERPs). Perceptual brain processing following electrophysiological responses to motor, sensory, and cognitive stimuli are reflected in ERPs (Horev, Most, & Pratt, 2007). Measurements of how the brain reacts to auditory stimuli is displayed in ERPs and they provide insight into how speech processing occurs on a neural level (Näätänen, 1995).

The Mismatch Negativity

The MMN is an event related potential that provides information regarding speech perception. The MMN is elicited passively through the use of an oddball paradigm (Kraus & McGee, 1994). In an oddball paradigm, a sequence is presented whereby a “standard” stimulus occurs at a higher rate of probability than an “oddball” stimulus. The MMN is typically observed between 150 to 250 milliseconds following presentation of the oddball stimulus (Näätänen, Paavilainen, Rinne, & Alho, 2007). The MMN is known to be present when a difference between two sensory stimuli is detected and has been shown to be sensitive enough to detect changes in interstimulus interval, sensory stimuli, and stimulus duration (Kraus & McGee, 1994). Furthermore, previous research has shown that the strength of the MMN is dependent on the extent of the differences between the acoustic stimuli (Näätänen et al., 2007).
Kraus, McGee, Sharma, Carrell, and Nicol (1992) demonstrated that the MMN is robust enough to be used diagnostically across adults and school-age children. Furthermore, Kraus et al. suggested that the absence of, or abnormalities in, the MMN could be indicative of a pathology or errors in speech processing. Cheour et al. (1998) elicited the MMN response in infants through recorded speech sounds and determined that the MMN is developmentally stable and does not change depending on the age of the individual. Furthermore, Sharma and Dorman (2000) suggested that the MMN occurs in language specific regions of the cortex when differing speech stimuli are presented.

**Statement of Purpose**

The current study sought to determine, through recording the MMN, differences in the brain’s processing of speech phonemes between young adult participants when compared to a normal and hearing-impaired geriatric participant. Specifically, the study sought to determine if, during the process of speech perception, the geriatric hearing-impaired participants required increased time and resources for the MMN response to occur. It is hypothesized that the geriatric hearing-impaired participants will experience a decreased strength in the MMN response.

**Method**

The purpose of this study was to monitor brain electrical activity in order to assess how the brain responds to speech stimuli in individuals 60-80 years-of-age by recording the MMN.

**Participants**

Eight healthy, older adults (ages 60 to 80 years; four male, four female), and 10 young adult controls (ages 18 to 30 years; five male, five female) participated in the study. The young adult participants presented with normal hearing thresholds of 20 dB HL or less for pure tones at frequencies 500, 1000, 2000, and 4000 Hz, bilaterally (American National Standards Institute,
Within the older adult participants, four participants presented with normal hearing and four presented with impaired hearing, i.e., thresholds above 20 dB HL for pure tones at frequencies 500, 1000, 2000, and 4000 Hz, bilaterally. All participants were right handed (Knecht et al., 2000) and self-reported no history of neurological, cognitive, or learning impairments. Each participant read and signed an informed consent document approved by the Institutional Review Board at Brigham Young University. Participants received $25 for their participation in the study.

**Stimuli**

The English phonemes /ba/ and /ga/ were digitally recorded by an adult, female, native English speaker. The phonemes /ba/ and /ga/ were chosen because of their close relationships according to a distinctive feature analysis (Horev et al., 2007). The signal was recorded in a sound treated room using a Larson Davis 1.27 cm model 2541 microphone attached to a Larson Davis model 900 microphone preamplifier. A 7.62 cm foam windscreen was used on the microphone at 0 degrees azimuth. The microphone preamplifier was attached to a Larson Davis model 2200 preamplifier power supply. The audio signal was digitized with 24-bit quantization and a 44.1 kHz sample rate using a Benchmark ADC1 analog-to-digital converter. The digital output of the Benchmark ADC1 was routed digitally to a SADiE digital editing station using version 5.5.4 software. Files were then saved as 24-bit wav files. The speaker sustained the /ba/ phoneme for 447 ms and the /ga/ phoneme for 476 ms. In order to establish discriminability and loudness equivalence between the /ba/ and /ga/ phonemes, two judges (one male, one female) were asked to listen to the recordings. The judges appropriately distinguished the phonemes and perceived the loudness level of each recording to be equal.
Procedures

**Initial screening.** In order to be included in the study, young adult participants were required to pass an initial hearing screening with pure tone thresholds ≤ 20 dB HL for octave intervals between 500-4000 Hz. Older adults were required to pass an initial hearing screening with pure tone thresholds ≤ 40 dB HL for 500-4000 dB HL. Following screening within the older adult participants, participants were separated into a normal hearing (thresholds of 20 dB HL or less for pure tones at frequencies 500, 1000, 2000, and 4000 Hz, bilaterally) and a hearing-impaired group (thresholds above 20 dB HL and below 40 dB HL for pure tones at frequencies 500, 1000, 2000, and 4000 Hz, bilaterally).

**EEG data collection.** Participants were fitted with a 64-channel Quick-Cap (Compumedics Neuroscan, 2018). The Quick-Cap was equipped with silver-silver chloride electrodes that rested against the scalp and were distributed according to the 10-20 International System (Jasper & Radmussen, 1958; Jurcak, Tsuzuki, & Ippeita, 2007). Six additional silver-silver chloride electrodes were placed on the right and left mastoid process, the outer cantha of each eye, and at approximately one inch above and below the supraorbital foramen of the left eye (to monitor eye movement and facial muscle activity). Electrodes were digitized to their location and impedances did not exceed 3000 ohms. A standard computer equipped with CURRY 7 software (EEG data collection; Compumedics Neuroscan, 2008) and ePrime-3 software (visual stimulus presentation; Psychology Software Tools, 2016) was used for EEG data collection and stimulus presentation.

**Data acquisition.** Participants were seated in a double-walled, sound treated test booth. Noise levels were within the limits as specified by ANSI S3.1-1999 R2008, Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms. The participants remained
seated throughout the duration of the session. Sound stimuli were presented through Etymotic EA-3 insert earphones and a Grason-Stadler model GSI-10 audiometer was used for stimulus presentation. The participants sat in a padded armchair which provided neck and head support for the duration of the data acquisition period. Additionally, participants were placed in front of a TV monitor 80 cm in front of them, which read:

You will watch a silent video on this screen. While you are watching the video, we will play a series of syllables through the headphones. You don’t need to respond to what you hear. Please keep your attention on the video.

Following reading the screen, the phonemes /ba/ and /ga/ were presented to the participant using an oddball paradigm at 50 dB HL. Participants were instructed to sit quietly and watch the movie presented on the TV monitor. Following four trial presentations of the standard stimulus, all sounds were presented randomly to the participant. The /ba/ phoneme was used as the standard stimulus in 50% of the participants and the /ga/ phoneme was used as the standard stimulus in the other 50% of the participants. Presentation of the /ba/ and /ga/ phoneme as the standard stimulus was randomized between participant groups. An interstimulus interval rate of 1.1 seconds was employed during the presentation of the stimuli. An EEG sample rate of 1 KHz and a common average as reference were employed. The EEG recording session lasted 16 minutes for a total of 120 trials. The ongoing EEG data were streamed onto the computer using CURRY 7 software and saved for post hoc averaging of the MMN. A StimTracker (Cedrus Corporation, 2018) was used in order to place event markers in the EEG recordings (onset of stimuli, auditory type, and stimulus code). The participants’ EEG were recorded and stored on a secure digital computer for off-line processing.
Data Analysis

The programs used in data acquisition and analysis revealed information regarding the electrical activity in the brain when hearing the phonemes /ba/ and /ga/. Artifacts such as eye and jaw movement were removed as part of the artifact removal procedure embedded in the CURRY 7 software. Epochs were created from the raw EEG data and recordings were individually investigated. All collected data resulting from artifacts were removed prior to compiling averages. Individual averages were calculated by averaging the ERP data and file averages were obtained from –100ms to 700ms following stimulus presentation. Two grand averaged ERP files were obtained by further averaging the individual averaged ERP files for each stimulus. A difference ERP file was created for MMN response analysis by subtracting the oddball ERP average from the common ERP (Aaltonen, Etroloa, Lang, Uusipaikka, & Tuomainen, 1994). The CURRY 7 neuroimaging software was used to calculate a density construction using sLORETA. Locations for each density constructions were compared between individuals. Cortical localization of speech stimuli was reconstructed with the CURRY 7 software, post hoc.

Measurements of start latency, the latency at the beginning of the MMN measured from a 30% negativity change in the amplitude of the MMN from baseline; cursor latency, the latency of the maximum negativity of the MMN; and end latency, the latency at the end of the MMN measured from a 60% change in amplitude as the MMN returned to the baseline. The amplitude of the MMN was measured from the maximum negativity of the MMN. Latencies were measured in ms and amplitude was measured in μA/mm².

Results

Event related potentials were obtained for each condition of stimulus presentation (standard and oddball). Furthermore, grand averages for each condition were calculated.
Additionally, a difference average, where the standard and oddball conditions were compared, was calculated. For the grand averaged ERP files, CURRY 7 was utilized in order to obtain dipoles and cortical source localization estimates of electrical activity (Compumedics Neuroscan, 2008). The location of dipoles was obtained using the grand averaged ERP files and then compared between the oddball and standard responses. Brodmann areas (BA) were identified, where possible, for each condition (Strotzer, 2009). Brodmann Areas were aligned with activation markers in order to obtain increased information regarding the brains function. The Cortical Functions Reference Manual was used to obtain the most accurate information regarding areas of activation within the brain (Trans Cranial Technologies, 2012). Table 1 contains the statistical analysis of the latency and amplitude of MMN in the participant groups.

Four participant averages were computed at random in order to avoid bias in the comparison of young adult participants to the geriatric participants. Additionally, all 10 young adult participant latencies and amplitudes were computed. When comparing four randomized participants, the young adult participants experienced a start latency at 148 ms, cursor latency at 167 ms, end latency at 185 ms, and amplitude of -0.63 μA/mm². When comparing 10 participants, the young adult participants experienced a start latency at 171 ms, cursor latency at 192 ms, end latency at 213 ms, and amplitude of -0.86μA/mm². The geriatric normal hearing participants experienced a start latency at 173 ms, cursor latency at 202 ms, end latency at 229 ms, and amplitude of -1.08μA/mm². The geriatric hearing-impaired participants experienced a start latency at 177 ms, cursor latency at 200 ms, end latency at 222 ms, and amplitude of -1.08μA/mm².
Table 1

Descriptive Statistics

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>M</th>
<th>SD</th>
<th>SE</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Young Adult</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start Latency</td>
<td>4</td>
<td>148.75</td>
<td>16.88</td>
<td>8.44</td>
<td>40.00</td>
</tr>
<tr>
<td>Cursor Latency</td>
<td>4</td>
<td>166.50</td>
<td>19.77</td>
<td>9.89</td>
<td>47.00</td>
</tr>
<tr>
<td>End Latency</td>
<td>4</td>
<td>184.50</td>
<td>24.23</td>
<td>12.11</td>
<td>59.00</td>
</tr>
<tr>
<td>Amplitude</td>
<td>4</td>
<td>-0.63</td>
<td>0.31</td>
<td>0.015</td>
<td>0.70</td>
</tr>
<tr>
<td>Start Latency</td>
<td>10</td>
<td>171.40</td>
<td>24.76</td>
<td>7.83</td>
<td>69.00</td>
</tr>
<tr>
<td>Cursor Latency</td>
<td>10</td>
<td>192.10</td>
<td>27.29</td>
<td>8.63</td>
<td>84.00</td>
</tr>
<tr>
<td>End Latency</td>
<td>10</td>
<td>212.60</td>
<td>30.23</td>
<td>9.56</td>
<td>100.00</td>
</tr>
<tr>
<td>Amplitude</td>
<td>10</td>
<td>-0.86</td>
<td>0.56</td>
<td>0.18</td>
<td>1.90</td>
</tr>
<tr>
<td><strong>Geriatric Normal Hearing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start Latency</td>
<td>4</td>
<td>172.75</td>
<td>13.50</td>
<td>6.75</td>
<td>33.00</td>
</tr>
<tr>
<td>Cursor Latency</td>
<td>4</td>
<td>201.75</td>
<td>17.56</td>
<td>8.78</td>
<td>40.00</td>
</tr>
<tr>
<td>End Latency</td>
<td>4</td>
<td>229.00</td>
<td>21.09</td>
<td>10.54</td>
<td>45.00</td>
</tr>
<tr>
<td>Amplitude</td>
<td>4</td>
<td>-1.08</td>
<td>0.46</td>
<td>0.23</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Geriatric Hearing Impaired</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start Latency</td>
<td>4</td>
<td>177.50</td>
<td>24.66</td>
<td>12.33</td>
<td>53.00</td>
</tr>
<tr>
<td>Cursor Latency</td>
<td>4</td>
<td>200.00</td>
<td>26.12</td>
<td>13.06</td>
<td>57.00</td>
</tr>
<tr>
<td>End Latency</td>
<td>4</td>
<td>222.00</td>
<td>25.59</td>
<td>12.79</td>
<td>56.00</td>
</tr>
<tr>
<td>Amplitude</td>
<td>4</td>
<td>-1.08</td>
<td>0.67</td>
<td>0.33</td>
<td>1.50</td>
</tr>
</tbody>
</table>

*Note:* Start latency = latency value (ms) at the beginning of the MMN; Cursor latency = latency value (ms) at the maximum amplitude of the MMN; End latency = latency at the end of the MMN; Amplitude = maximum MMN amplitude (86μA/mm²).

Figures 1 through 4 display four views: coronal, sagittal, axial and a scalp distribution. Colored areas represent averaged regions of activation within the participants during the presentation of the stimulus (standard, oddball, and difference). Each area was labeled with a number to aid in the localization of brain activity. Following references to each area, a corresponding number representing that area is displayed in parentheses. The scalp distribution represents the spread of energy following stimulus presentation and high levels of activity are represented by higher concentrations of color.
Figure 1. Brain activation response in young adult participants.
Figure 2. Brain activation response in the geriatric normal hearing participants.
Figure 3. Brain activation response in the geriatric hearing-impaired participants.
Figure 4. Brain activation response in comparisons between participants.

The mean global field power (MGFP) is displayed in Figures 1, 2 and 3. The MGFP is the sum of squares of each channel for each time point, thus representing the degree of activity at each time point. Stimuli were presented at the marker “0 ms” and the MMN is represented on the waveform by other listed time markers. The figures represent the cortical areas of activation during different conditions and participant groups. The MGFP exists as a reference point for the cortical activation diagrams.

Figure 1 displays the young adult participants. Within the young adult participants, activity was observed across all presentation types in the parahippocampal gyrus (5), the
superior temporal gyrus (1), BA 22 (2), BA 41 (3), BA 20 (15), and BA 13 (20). The parahippocampal gyrus is associated with memory encoding and retrieval. The superior temporal gyrus, BA 22, and BA 41 are part of the auditory cortex and allow for the processing of auditory information. Brodmann Area 20 is associated with visual processing and BA 13 is associated with emotional control. The young adult standard and oddball conditions displayed activity in the inferior temporal gyrus (14). Similar to BA 20, the inferior temporal gyrus is important in visual processing. The oddball condition and difference conditions displayed activity in BA 28 (16), which is part of the entorhinal cortex and is the main communication area between the hippocampus (memory) and the neocortex (sight and hearing). Activity was also seen in the corpus callosum (24), which allows for the integration of motor, sensory, and cognitive information between the cerebral cortex. Within the young adult standard condition, activity was observed in BA 6 (4), which functions as part of the premotor cortex. The premotor cortex is highly involved in movement planning. The young adult oddball condition displayed activity in BA 35 (6) and BA 36 (7). These areas function as part of the perhinial cortex and are important for cortical locations for memory. Additionally, activity was observed in the right hemisphere in the postcentral gyrus (9) and BA 1 (8); which are part of the primary sensory cortex and allows for the processing of sensation from the body. The young adult difference condition displayed, activity in the superior frontal gyrus (10) and the medial frontal gyrus (11). These areas aid in decision making and information processing. Activity was observed in BA 18 (27) and the middle occipital gyrus (33), which aid in the processing of visual information. The scalp distribution of the young adult standard condition displayed positivity in the frontal and parietal lobes. The frontal lobe aids in problem solving, memory, language, judgment, and impulse control. The parietal lobe functions in the process of sensory integration. Negativity was
displayed in the temporal lobes and the occipital lobes. The temporal lobe allows for speech processing to occur and the occipital lobe aids in the processing of visual information. The scalp distribution of the young adult oddball stimuli displayed a positivity in the left parietal lobe and a negativity in the left occipital and temporal lobes. The scalp distribution of the young adult difference displayed a negativity in the right parietal lobe and positivity in the left temporal lobe.

Figure 2 displays the geriatric normal hearing participants. Within the geriatric normal hearing participants, activity was seen in the middle temporal gyrus (22), the parahippocampal gyrus (5), BA 13 (20), and the inferior frontal gyrus (17) across all presentation types. The middle temporal gyrus is thought to contribute to the understanding of written text and facial recognition. The parahippocampal gyrus is associated with memory encoding and retrieval. Brodmann Area 13 is associated with emotional control, and the inferior frontal gyrus is associated with language processing and speech production. The geriatric normal hearing standard and geriatric normal hearing oddball conditions both displayed activity in BA 37, which is a part of the fusiform gyrus associated with recognition. Activity was seen in BA 22 (2), which is associated with the auditory cortex and allows for the processing of auditory information. Activity was seen in BA 20 (15) and BA 28 (16). Brodmann Area 20 is associated with visual processing and BA 28 is part of the entorhinal cortex and is the main communication area between the hippocampus (memory) and the neocortex (sight and hearing). The geriatric normal hearing oddball and geriatric normal difference condition displayed activity in BA 47 (19), which is associated with language processing and speech production. Within the standard and difference conditions, the middle frontal gyrus (11), which aids in decision making and information processing, displayed activity. The geriatric normal hearing standard condition displayed activity in BA 35 (6), which is a part of the perihinal cortex and is important for
cortical locations associated with memory. Within the geriatric normal hearing oddball condition, activity was observed in BA 36 (7). Similar to BA 35, BA 36 is part of the perihinial cortex and performs the same functions. Activity in the substantia nigra (18) in the left hemisphere was observed. The substantia nigra plays an important role in movement. Within the geriatric normal hearing difference results, activity was seen in BA 11 (35), which is associated with decision making. The scalp distribution of the geriatric normal hearing standard condition displayed diffuse positivity across the left and right frontal and parietal lobes. Furthermore, a negativity was observed in the left temporal lobe. The scalp distribution of the geriatric normal hearing oddball condition displayed positivity in the right frontal and temporal lobe. Additionally, negativity was observed in the occipital lobes. The scalp distribution for the geriatric normal hearing difference displayed a negativity in the left parietal lobe and specific locations for positivity could not be localized.

Figure 3 displays the geriatric hearing-impaired participants. Within the geriatric hearing-impaired participants, activity was observed across all presentation types in the parahippocampal gyrus (5), BA 13 (20), the superior temporal gyrus (1), and the middle temporal gyrus. The parahippocampal gyrus is associated with memory encoding and retrieval. Brodmann Area 13 is associated with emotional control. The superior temporal gyrus plays an important role in the comprehension of written and spoken language and the middle temporal gyrus aids in accessing word meaning through written text and facial recognition. Within the geriatric hearing-impaired participants, the standard and oddball condition activity was seen in the BA 20 (15) and the inferior temporal gyrus (14), which are associated with visual processing. BA 28 (16) displayed activation and is the main communication area between the hippocampus (memory) and the neocortex (sight and hearing).
Additionally, BA 36 (7) displayed activation, which is associated with the perirhinal cortex and is important for cortical locations associated with memory. Within the geriatric hearing-impaired standard and difference results, activity was observed in the thalamus (31) and BA 38 (36). The thalamus helps relay information to different areas of the cortex and BA 38 helps in semantic processing, speech comprehension, and naming. Specific activation in the geriatric hearing-impaired difference results revealed activity in the superior frontal gyrus and the middle frontal gyrus. The superior frontal gyrus and middle frontal gyrus serve in decision making and information processing. The scalp distribution in the geriatric hearing-impaired standard condition displayed positivity in the left parietal and frontal lobe. Negativity was located in the temporal and occipital lobes. The scalp distribution of the geriatric hearing-impaired oddball condition showed positivity in the frontal lobes and negativity in the temporal lobes. The geriatric hearing-impaired difference scalp distribution displayed a positivity in the right temporal and occipital lobes.

Figure 4 displays the comparisons between the populations. Activity was observed across all results in the parahippocampal gyrus (5), BA 36 (7), BA 20 (15), and the inferior temporal gyrus (14). The parahippocampal gyrus is associated with memory encoding and retrieval. Brodmann area 36 is part of the perirhinal cortex and is important for cortical locations associated with memory. Brodmann area 20 and the inferior temporal gyrus are both associated with visual processing. The comparison between the geriatric hearing-impaired participants versus the young adult participants, and the young adult participants versus the geriatric normal hearing participant, revealed similarities in activity in BA 4 (25) and the precentral gyrus (42). Brodmann area 4 and the precentral gyrus are associated with motor planning and initiation. Furthermore, activity was observed in BA 21 (26), which is associated with obtaining word
meaning from text and facial recognition. Lastly, activity was observed in BA 38, which is thought to aid in the integration of perceptual limits with emotional responses. No specific similarities were observed in the comparison of the young adults to the geriatric normal hearing and the geriatric normal hearing to the geriatric hearing-impaired participants. Additionally, no specific similarities were observed in the comparison of the geriatric normal hearing to the geriatric hearing impaired and the geriatric hearing impaired to the young adult participants. Scalp distribution in the young adult compared to the geriatric normal hearing participants showed a negativity in the left frontal and parietal lobe. Furthermore, positivity was observed in the left and right temporal lobes. The scalp distribution of the young adult compared to the geriatric hearing-impaired participants displayed a negativity in the left frontal and parietal lobe. Positivity was identified in the left and right temporal lobes. The scalp distribution of the geriatric hearing-impaired compared to the geriatric normal hearing participants revealed negativity in the left frontal and parietal lobe and positivity could not be identified.

**Discussion**

This study sought to determine, using the MMN, if there was a difference in brain processing of speech phonemes between the young adult participants, the geriatric normal hearing participants, and the geriatric hearing-impaired participants. It was hypothesized that the geriatric hearing-impaired participants will experience a decreased strength in the MMN response.

**Summary and Evaluation of Results**

**Young adult participants.** The young adult participants required less processing time in order to identify the difference between the two phonemes. For example, the MMN occurred and ended earlier in the young adult participant than in the other participants. The decreased latency
in the young adult participants suggest that they are able to distinguish differences in speech sounds more efficiently than the geriatric normal hearing and the geriatric hearing-impaired participants. Furthermore, the young adult participants may experience an easier time predicting the correct response and hence reduces processing time. Additionally, the young adult participants experienced decreased amplitudes of the MMN. The lower amplitudes would suggest that there is not a large processing difference and that they are able to recognize that the phonemes presented are correct and not an incongruity. As mentioned previously, the MMN is known to be developmentally stable (Cheour et al., 1998). The difference in amplitude and latency between the young adult participants and the geriatric participants suggests that cognitive factors resulting from aging influence MMN results.

Activity over the left superior temporal gyrus was seen for all conditions tested in the young adult participants. However, the young adult standard condition displayed higher activity in the left superior temporal gyrus than in the other conditions. The superior temporal gyrus is closely associated with BA 22, which is also known as Wernicke's area. Wernicke’s area plays a crucial role in speech perception and understanding. The activity in Wernicke’s area suggest that the young adult participants are using the appropriate resources for speech perception to occur.

In the young adult oddball condition, activity is observed in the right parahippocampal gyrus and BA 35. The parahippocampal gyrus is associated with memory encoding and retrieval and BA 35 is also associated with memory. The activity in the parahippocampal gyrus and BA 35 suggest that memory plays an important role in the identification of oddball stimuli. The young adult difference comparison between the two conditions indicated that the largest dissonance was located within the left superior temporal gyrus. The dissonance in this area between the standard and oddball conditions suggests that within the young adult participants, the superior temporal
gyrus plays a larger role in standard stimuli presentation than in oddball stimuli presentation. The locations of activity in the young adult participants differs from that observed by Sharma and Dorman (2003), who suggested that the MMN occurs in language specific regions of the cortex when differing speech stimuli are presented. During the presentation of the standard stimuli the young adult participants displayed activity in Wernicke’s area, which is known to be associated with language processing. Furthermore, during the presentation of the oddball stimuli, the young adult participants displayed activity in the parahippocampal gyrus and BA 35, which are associated with memory. Although not conclusive, the localization of activity for the standard stimuli to a language associated area and the oddball stimuli to a memory associated area suggests that differing speech stimuli may not be always processed in specific language areas of the brain. Additionally, the variations between cortical locations of the oddball and standard conditions in the young adult participants suggest that different processing is used for different types of stimuli.

The scalp distribution of the young adult standard condition displays low level diffuse energy centralized in the left temporal lobe. However, the young adult oddball condition displays a moderate level of energy centralized in the left parietal lobe and occipital lobes. The scalp distribution of the young adult participants confirms the previous noted cortical locations for speech perception. However, the difference in the strength of the response between the standard and oddball condition suggests that the identification of the standard stimulus requires less brain resources than the identification of an oddball stimulus.

**Geriatric normal hearing participants.** The MMN for the geriatric normal hearing participants appeared to start 4 ms earlier than the geriatric hearing-impaired participants and 2 ms later than the young adult participants (N = 10). However, the MMN for the geriatric
normal hearing participants ended 7 ms later than the geriatric-hearing impaired participants and 16 ms (N = 10) later than the young adult participants. This observation suggests that the geriatric normal hearing participants may take longer to processes speech differences when compared to the geriatric hearing-impaired participants and the young adult participants. The amplitude of the MMN in the geriatric normal hearing participants is higher than the young adult participants, but is equivalent to the geriatric hearing-impaired participants. The increased amplitude of the response suggests that they are recognizing the two phonemes as having greater incongruity than within the young adult participants.

The parahippocampal gyrus appeared to play a major role in both the geriatric normal hearing standard and oddball conditions. The parahippocampal gyrus is associated with memory encoding and retrieval. Additionally, the oddball condition appeared to have activity present in BA 28, which is the main communication area between the hippocampus (memory) and the neocortex (sight and hearing). The difference comparison between the two conditions revealed that the greatest difference in activity between the two lay in the middle frontal gyrus. The results suggest that the geriatric normal hearing participants relies on the memory components of the brain for speech perception to occur in all conditions. Additionally, when a standard speech stimulus is presented, the frontal lobe aids in decision making and information processing, and when an oddball stimulus is presented, the brain must link sensory information with memory.

The scalp distribution of the geriatric normal hearing standard condition displays low level diffuse energy centralized in the frontal and occipital lobes. Also, the geriatric normal hearing oddball condition displays a low level of energy centralized in the right parietal lobe and left occipital lobes. The scalp distribution suggests that the geriatric normal hearing participants
use less resources during the process of speech perception than when compared to other participants. The reduction in resources may contribute to the increased latency of the MMN.

**Geriatric hearing-impaired participants.** The MMN for the geriatric hearing-impaired participants appeared to start 5 ms later than the geriatric normal hearing participants and 7 ms (N=10) later than the young adult participants. However, the MMN for the geriatric hearing-impaired participants ended 7 ms earlier than the geriatric normal hearing participants and 9 ms (N=10) later than the young adult participants. Similar to the geriatric normal hearing participants, the amplitude of the geriatric hearing-impaired participants suggests that they are recognizing the two phonemes as having greater incongruity than the young adult participants.

The standard condition appeared to have the highest amount of activity located in BA 28 and the oddball condition appeared to have the highest amount of activity located in the superior temporal gyrus. The difference between the two conditions revealed the highest dissonance in the middle frontal gyrus. This information suggests that in the geriatric hearing-impaired participants, sensory integration and information processing are important in understanding standard speech stimuli. Additionally, oddball stimuli require input from the auditory cortex in order to be processed.

The scalp distribution for the standard and oddball condition in the geriatric hearing-impaired participants displayed a high concentration of activity in the left parietal, temporal, and occipital lobes. The scalp distribution did not display a localization of high energy concentration in one cortical location and no dramatic differences were observed between the standard and oddball presentations. The results suggest that the geriatric hearing-impaired participants require increased effort for speech perception to occur based on the increased latencies of the geriatric participants. The increased amount of activity in the geriatric hearing-impaired participants may
contribute to the increased latency when compared to the young adult participants. The increased areas of activation may result in longer speech processing time in the geriatric-hearing impaired participants. Furthermore, the lack of localization of energy concentration may result in delayed speech perception.

**Comparisons between participants.** The comparison between the young adult, geriatric normal hearing, and the geriatric hearing-impaired participants displayed many of the same cortical locations and distributions of energy. All comparisons displayed a high level of activity in BA 36. The comparison between the geriatric hearing-impaired and the geriatric normal hearing displayed activity in the parahippocampal gyrus. Activity in BA 36 and the parahippocampal gyrus suggest that different types of cortical components involved in memory play an important role in speech processing in the young adult and geriatric participants. Additionally, the geriatric hearing-impaired and the geriatric normal hearing comparison demonstrated activity in the corpus callosum, suggesting that the geriatric participants require more communication between the hemispheres for speech perception to occur.

**Limitations of the Study and Directions for Future Research**

This study would be strengthened by a larger sample size and greater diversity of participants. This would allow for the results of this study to be generalized to the population as a whole. The range in hearing abilities within the geriatric hearing-impaired population may have influenced results from the study. Shiga et al. (2001) suggested that variations in the intensity of a stimulus have an effect on the latencies of evoked potentials. Therefore, the 30 dB range afforded to the hearing-impaired population may have influenced the latencies of the MMN in the geriatric hearing-impaired population. Future research may focus on establishing loudness
equivalent between populations such that consistency within the presentation level of the stimuli is adjusted.

Furthermore, the lack of a young adult hearing-impaired group may have limited the study in providing further evidence regarding aging and the presence of the MMN. Future research may include this population sample in order to establish a strong link in the relationship between cognitive decline and hearing loss. Additionally, a population sample of an aided geriatric hearing-impaired group may provide evidence regarding the influence of hearing loss on the MMN and the helpfulness of aided technology.

Due to the necessity of repeated measures in this study, priming may have occurred throughout the phoneme tasks. Laufer, Negishi, Lacadie, Papademetris, and Constable (2011) found that when performing an oddball paradigm experiment, the right middle frontal gyrus produced a less inhibited response during the presentation of the oddball condition, when compared to the standard condition presentation. The study concluded that depending on the stimulus presented, the brain’s response could be altered. Therefore, the repeated measures in this study may have biased the presentation of the MMN.

While qEEG provides accurate spatial resolution, the use of fMRI for data collection and presentation would have allowed for more detailed information regarding cortical location sites for all participant groups. The qEEG data obtained in this study may be used to analyze amplitudes of the brain’s response to provide information regarding the amount of resources required for speech perception to occur.

**Conclusion**

This study sought to determine, using the MMN, if there was a difference in the brain’s processing of speech phonemes between the young adult participants, the geriatric normal
hearing participants, and the geriatric hearing-impaired participants. Through analysis of a passive language task, cortical localization, and brain mapping, results concluded that the young adult participants processed speech sounds at a faster rate when compared to the geriatric normal hearing and the geriatric hearing-impaired participants. Furthermore, results concluded that the geriatric normal hearing and the geriatric hearing-impaired participants displayed many of the same cortical language processing locations. The findings have the potential to influence the treatment of individuals with hearing-loss as a result of old age. It is essential to consider the limitations of the current experiment due to the novel nature of this experiment.
References


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 include 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

**Figure Key**

Key Pertaining to Cortical Location Labels in MMN Figures

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Superior Temporal Gyrus</td>
<td>Processing of auditory information</td>
</tr>
<tr>
<td>2</td>
<td>BA 22</td>
<td>Processing of auditory information</td>
</tr>
<tr>
<td>3</td>
<td>BA 41</td>
<td>Processing of auditory information</td>
</tr>
<tr>
<td>4</td>
<td>BA 6</td>
<td>Movement planning</td>
</tr>
<tr>
<td>5</td>
<td>Parahippocampal gyrus</td>
<td>Memory encoding and retrieval</td>
</tr>
<tr>
<td>6</td>
<td>BA 35</td>
<td>Cortical locations for memory</td>
</tr>
<tr>
<td>7</td>
<td>BA 36</td>
<td>Cortical locations for memory</td>
</tr>
<tr>
<td>8</td>
<td>BA 1</td>
<td>Processing of sensory information</td>
</tr>
<tr>
<td>9</td>
<td>Postcentral gyrus</td>
<td>Processing of sensory information</td>
</tr>
<tr>
<td>10</td>
<td>Superior Frontal Gyrus</td>
<td>Decision making and information processing</td>
</tr>
<tr>
<td>11</td>
<td>Middle Frontal Gyrus</td>
<td>Decision making and information processing</td>
</tr>
<tr>
<td>12</td>
<td>BA 37</td>
<td>Recognition</td>
</tr>
<tr>
<td>13</td>
<td>BA 34</td>
<td>Word recognition</td>
</tr>
<tr>
<td>14</td>
<td>Inferior Temporal Gyrus</td>
<td>Visual processing</td>
</tr>
<tr>
<td>15</td>
<td>BA 20</td>
<td>Visual processing</td>
</tr>
<tr>
<td>16</td>
<td>BA 28</td>
<td>Communication between hippocampus and neocortex</td>
</tr>
<tr>
<td>17</td>
<td>Inferior Frontal Gyrus</td>
<td>Language processing and speech production</td>
</tr>
<tr>
<td>18</td>
<td>Substantia Nigra</td>
<td>Movement</td>
</tr>
<tr>
<td>19</td>
<td>BA 47</td>
<td>Language processing and speech production</td>
</tr>
<tr>
<td>21</td>
<td>Hippocampus</td>
<td>Memory</td>
</tr>
<tr>
<td>22</td>
<td>Middle Temporal Gyrus</td>
<td>Understanding written text and facial recognition</td>
</tr>
<tr>
<td>23</td>
<td>BA 10</td>
<td>Memory encoding, retrieval, and working memory</td>
</tr>
<tr>
<td>24</td>
<td>Corpus Callosum</td>
<td>Integration of motor, sensory, and cognitive information within the cerebral cortex</td>
</tr>
<tr>
<td>25</td>
<td>BA 4</td>
<td>Motor Planning and initiation</td>
</tr>
<tr>
<td>26</td>
<td>BA 21</td>
<td>Undefined</td>
</tr>
<tr>
<td>27</td>
<td>BA 18</td>
<td>Visual information processing</td>
</tr>
<tr>
<td>28</td>
<td>BA 19</td>
<td>Processing of phonological properties</td>
</tr>
<tr>
<td>29</td>
<td>BA 9</td>
<td>Auditory Imagery</td>
</tr>
<tr>
<td>30</td>
<td>BA 25</td>
<td>Emotional language</td>
</tr>
<tr>
<td>31</td>
<td>Thalamus</td>
<td>Relays information to different areas of the cortex</td>
</tr>
<tr>
<td>32</td>
<td>BA 23</td>
<td>Attention to speech and language comprehension</td>
</tr>
<tr>
<td>33</td>
<td>Middle Occipital Gyrus</td>
<td>Processing visual information</td>
</tr>
<tr>
<td>34</td>
<td>Insula</td>
<td>Emotional processing, attention, and decision making</td>
</tr>
<tr>
<td>35</td>
<td>BA 11</td>
<td>Decision making</td>
</tr>
<tr>
<td>36</td>
<td>BA 38</td>
<td>Semantic processing, speech comprehension, and naming</td>
</tr>
<tr>
<td>37</td>
<td>Inferior Parietal Lobe</td>
<td>Interpretation of sensory information</td>
</tr>
<tr>
<td>38</td>
<td>BA 40</td>
<td>Sensory integration and language comprehension</td>
</tr>
<tr>
<td>Area</td>
<td>Function</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>BA 29</td>
<td>Motor learning, language comprehension, and memory retrieval</td>
<td></td>
</tr>
<tr>
<td>BA 32</td>
<td>Memory encoding, retrieval, and working memory</td>
<td></td>
</tr>
<tr>
<td>Precentral Gyrus</td>
<td>Motor planning and initiation</td>
<td></td>
</tr>
</tbody>
</table>

APPENDIX C

Annotated Bibliography


**Objective:** This study evaluated how the mismatch negativity was influenced by vowel pitch and formant frequency. **Methods:** Participants included nine females and seven males between the ages of 21 and 52. Each participant was fitted with 21 silver-silver chloride electrodes. Following placement of the electrodes, recorded vowels and pure tones were presented to the participant through earphones. Stimuli included sixteen pairs of standard and deviant vowels that differed in fundamental frequency and second formant frequencies, which were matched with pure tone frequencies as a control. In order to obtain the MMN the standard frequency was subtracted from the MMN. **Results:** The study showed the frequency changes in stimuli affect MMN amplitudes, but not the latencies. The MMN was determined to be present following presentation of a deviant stimuli, but more sudden results were present when the pure tone frequencies were presented. **Conclusions:** The MMN was known to be present across all situations presented within the study. Furthermore, reduced strength of the MMN was shown to be present with vowels at a 4% and 20% frequency difference. **Relevance to the current work:** This study determined that the MMN can be elicited through a variety of oddball paradigms. Furthermore, this study emphasized how to obtain the MMN when working with and employing an oddball paradigm.


**Objective:** This study evaluated the effects of various speech rates and competing noise on older adults with a hearing impairment. **Methods:** Participants included individuals age 56 to 81 years of age. Individuals were grouped according to the severity of their hearing loss (i.e. normal hearing older adults, hearing-impaired older adults). All participants were native English speakers. The stimuli used represented speech rates at 120 wpm, 170 wpm, and 234 wpm. Participants completed a nonmedical otoscopic examination. Participants were presented with stimuli at various speech rates and were asked to repeat each sentence heard in its entirety. Following presentation of stimuli, the participants responses were scored according to target words and the signal to noise ratio was calculated for each rate-altered condition. **Conclusion:** Participants with normal hearing achieved a lower signal to noise ration loss than those with hearing impairment. **Relevance to the current work:** This study concluded that individuals with hearing loss benefited from increased processing time. This study suggests that those with hearing loss use neurological resources with less efficiency.

**Objective:** The American Academy of Audiology Task Force publishes nationwide guidelines pertaining to the treatment of adults with hearing impairments. The guidelines outlined the process of assessment, goal setting, providing hearing aids and alternative technology, counseling, and assessment of outcomes. *Relevance to the current work:* These guidelines set the precedent for initial treatment of hearing loss to involve hearing amplification devices.


**Objective:** The American Speech-Language Hearing Association publishes nationwide guidelines pertaining the use of audiometers. The ANSI standards provides standards for the use of transducers in the assessment of individuals with hearing loss. *Relevance to the current work:* In the present study audiometers were calibrated according to ANSI standards.


**Objective:** The American Speech-Language-Hearing Association (ASHA) publishes nationwide guidelines pertaining to the ethical screening and assessment of individuals suspected of hearing loss. *Relevance to current work:* In order to be considered for additional qEEG investigation, each participant underwent a hearing screening in accordance with the guidelines set forth by ASHA.


**Objective:** Stimtracker software marks when certain stimuli are presented during EEG data collection. *Relevance to the current work:* Stimtracker software was used in the current study for the purpose of marking stimuli data.


**Objective:** The purpose of this study was to compare the MMN in infants at varying ages (pre-term infants, full-term newborns, and full-term 3-month-old infants). The study sought to determine if there was a difference in amplitude and latency when compared to each other. **Methods:** Participants included 12 pre-term infants, six full-term newborns, and 11 3-month-old infants. Stimuli was obtained through the use of the finish vowels /y/ and /i/. The sounds were presented at 75- dB HL lasting 100ms in blocks of 300. In each block the standard stimulus and deviant stimulus were randomly presented. Infants were in differing sleep-or waking states
throughout testing. Event related potentials were recorded from the infants during awake cycles, which was determined through the EEG patterns. ERP’s were collected through the use of electrodes placed on participants scalp. **Conclusion:** No significant differences were observed between the three age groups. Latency of MMN decreased with age. **Relevance to current work:** This study suggests that MMN is developmentally stable. Furthermore, study suggests that MMN amplitude resembles that of adults. This suggests that changes in age would not influence the MMN, but may be due to external factors.


**Objective:** This study focused on understanding the negative impact of age-related hearing loss. **Methods:** This study was obtained through a systematic review of peer reviewed articles related to age related hearing loss. **Conclusion:** Age related hearing loss leads to difficulty with communication. Furthermore, age related hearing loss can lead to social isolation and withdrawal from society. **Relevance to the current work:** This article lays claim to the idea that hearing loss can relate to withdrawal from society.


**Objective:** CURRY 7 software helps to overlay temporal data onto brain images and to identify the location of electrical activity. **Relevance to the current work:** CURRY 7 computer software was used in the current study for the purpose of source reconstruction and dipole localization.


**Objective:** NeuroScan 4.5 software records EEG data and provides the ability to process and edit data following collection. **Relevance to the current work:** NeuroScan 4.5 computer software was used in the current study during EEG data collection.


**Objective:** The electrode cap aids in the collection of electrical information from the participant. **Relevance to the current work:** All participants were fitted with a 64-electrode cap in order to obtain EEG data.


**Objective:** The purpose of this study was to determine if there is a difference in processing between individuals with and without aphasia. **Methods:** Participants included four aphasic
patients and four control subjects. Controls had no history of neurological impairment and were age matched to those with aphasia. Participants were right handed. Aphasia patients were chosen based on neuropsychological profiles representing Broca’s and Wernicke’s aphasia. Participants were diagnosed with types of aphasia according to the Western Aphasia battery. Participants were presented with three different types of stimuli (pure tones, front vowels and consonant vowels) in a passive oddball paradigm. Event related potentials were recorded through the use of electroencephalography while participants were presented with target stimuli. **Conclusion:** According to the MMN, participants with damage in the language processing areas of the brain displayed deficits in processing contrasting features, when compared to participants with unimpaired neurological systems. **Relevance to current work:** This study demonstrates a difference in the processing of neuro-atypical and neurotypical individuals. Furthermore, this study supports the exclusion of individuals with neurological impairment in the current study.


**Objective:** This study aimed at using standardized audiometric testing procedures and health-related quality of life measurements to determine the impact of hearing loss on communication, function, and health-related quality of life in the geriatric population. **Methods:** Population was obtained by a follow-up of the Epidemiology of Hearing Loss Study. Air- and bone conduction thresholds were obtained and pure-tone averages were calculated. Furthermore, The Hearing Handicap Inventory for the Elderly-Screening Version (HHIE-S) was used to determine how participants perceived their hearing loss. In addition to the HHIE-S participants were asked additional questions regarding communication difficulties in specific situations. Furthermore, the Short Form 36 Health Survey (SF-36) was employed in order to gain information regarding health-related quality of life in participants. **Conclusion:** Age related hearing loss leads to difficulty in communication which can lead to a reduced quality of life. The severity of a hearing loss is associated with lower scores relating to vitality, social functioning, role emotional, mental health, role physical, and physical functioning. **Relevance to the current work:** The degree of hearing loss relates to the likelihood of having a hearing handicap and a decline in the quality of life in the geriatric population.


**Objective:** The author outlines the primary mechanisms necessary for the processing of acoustic stimuli. The function of the outer, inner and middle ears is explained in relation to how sound is transferred to the brain. Furthermore, the role of the central nervous system in interpreting acoustic stimuli is outlined. **Relevance to current study:** This reference provides the necessary insight for understanding how acoustic stimuli is converted into meaningful sounds. Furthermore, this reference emphasizes the brains role in speech perception.

**Objective:** The purpose of this study was to address the difference between older adults and younger adults in neuroanatomical and functional foundation of auditory perception and speech processing. **Methods:** Participants included 23 healthy older adults and 13 younger adults. All participants scored at least a 26 on the mini-mental examination and had no history of neurological or psychiatric diseases. Furthermore, participants were monolingual, right handed, and had normal hearing. Each participant's pure-tone threshold was assessed in order to ensure normal hearing. Following pure-tone testing, each individual was tested for frequency selectivity, temporal compression, and speech intelligibility. A 128-electrode cap was used to continuously record the brain electrical activity for each participant throughout testing. Frequency selectivity included a forward-masking paradigm. The masking level would periodically decrease or increase in 2 dB steps. Throughout the process, participants would hear a tone and would be asked to indicate if they heard the tone. Temporal compression was assessed in a similar manner with a forward-masking paradigm; however, the masker and the probe varied in time (10, 30, 50, and 70ms). Speech intelligibility was measured using the Oldenburg Sentence Test. Each participant was presented with a sentence amongst a masking noise. The participant was instructed to repeat the sentence following presentation with as many words as possible. Throughout testing, the masking noise and presentation level was varied in order to attain a 50% correct response. Following speech intelligibility testing, cortical thickness was assessed from a 3.0 T Philips Ingenia scanner. **Results:** The frequency selectivity and temporal compression was lower in the older adults as compared to the younger adults. Older adults had a lower cortical thickness than younger adults. Stronger lateralization was seen in older adults rather than in younger adults. **Conclusion:** Auditory perception deficits in older adults cannot be attributed to peripheral hearing loss and cannot fully be examined through pure tone testing. Also, cortical thinning contributes to hearing loss in older adults and prosody plays a role in individuals being able to interpret auditory stimuli. **Relevance to the current work:** This study reveals a direct difference in auditory processing in the older adult and young adult population. Furthermore, this study provides evidence for the need of continued research in the area of geriatric hearing loss.


**Objective:** This study sought to determine if voicing perception was influenced by linguistic experience or innate temporal sensitivity by examining the electrophysiological correlates of speech Voice-Onset-Time (VOT) and non-speech Formant-Onset-Time (FOT). **Methods:** Participants included 14 normal hearing Hebrew Speakers. Participants were asked to identify and discriminate two different stimuli. Stimuli included a natural voice recording and a synthesized non-speech recording. The VOT of the natural voice recording, /ba/ and /pa/, was altered. Furthermore, the synthesized non-speech stimuli was composed of 2 formants that differed in their FOT. Data was obtained through the use of electroencephalography. Data was processed by deducting the deviant response from averaged data. **Results:** Results indicated the presence of the P300 (P3) response in speech stimuli and in deviant non-speech stimuli, but not in standard non-speech stimuli. Furthermore, VOT influenced the N1 latency and amplitude in addition to the P2 amplitude. Also, FOT influenced the P2 amplitude. **Conclusion:** Results suggest that voicing perception is influenced by linguistic experience. Additionally, it was determined that non-speech signals undergo different stages of auditory processing. **Relevance to**
The phonemes /ba/ and /pa/ used in this study differ in only one distinctive feature. Similarly, the phonemes used in our study /ba/ and /ga/ differ in one distinctive feature, as well. Furthermore, this study supports that event related potentials can be sensitive to motor, sensory, or cognitive stimuli.


Objective: This study sought to identify a relationship between rhinencephaly and neocortical subdivisions. Additionally, the study aimed at identifying the interrelationships between the temporal region of the brain with subcortical structures. Methods: Participants included 80 individuals (57 men and 23 women) who presented with temporal lobe seizures. A Grass depth electrode was used to stimulate the temporal lobe of the participants. The feelings associated with the electrical stimulation were recorded and reported. Results: Results varied in response to electrode stimulation for each participant; however, a strong correlation was identified in subcortical areas between participants. Conclusion: Motor, sensory, physical, and emotional responses were associated with varying cortical regions. Furthermore, there was very little influence on other areas of the brain during specific location testing. Relevance to the current work: The present study utilized the 10-20 system of electrode placement that was originally developed by Jasper.


Objective: The purpose of this research study was to determine the effectiveness of the 10/20 system as compared to other electrode placement data analysis systems. Methods: The MRI data sets of 17 healthy volunteers were obtained. The 10/20, 10/10, and 10/5 data positions were determined and their spatial variability was assessed. From each data system, researchers sought to determine if landmark positions could be determined. Results: Research concluded that when using the 10/20 system, the locations of cortical landmarks remain ambiguous. However, external land marking increased spatial data effectiveness. Conclusion: When using the 10/20 system, a more detailed rule for land marking provides more effective results. Relevance to the current work: The present study utilized digitization in accordance with the 10-20 system of electrode distribution to ensure more precise spatial data.


Objective: This study sought to determine the effects of hearing instrumentation on improving the quality of life of in individuals with hearing loss. Methods: Participants included 2,069 hearing-impaired individuals who did and did not use hearing instrumentation. Furthermore, 1,710 of their family members or friends were interviewed as well. Participants were surveyed according to their activity level, interpersonal relations, social effects, emotional effects,
personality, and health impact. The impact of hearing instruments on the aforementioned survey categories were analyzed using analysis of variance. **Results:** Individuals who used hearing instrumentation were more likely to engage in social activities, have greater warmth in relationships, suffer less from depressive symptoms and have improved overall health. Furthermore, individuals with hearing loss were more likely to pretend to hear what conversational partners had said and be classified as confused, disoriented, or non-caring. **Conclusion:** Impaired hearing negatively influences the quality of life in individuals; however, the use of hearing instruments as an aid can help reduce the negative effects. **Relevance to the current work:** This study supports the claim that hearing aids are needed as a treatment for individuals with hearing loss. Furthermore, this study explores the negative effects hearing loss has on the quality of life in individuals.


**Objective:** This study sought to understand brain lateralization in healthy right-handers and if deviations from dominance in the left hemisphere were indicative of pathologies. **Methods:** Participants included 188 healthy individuals between 17 and 40 years old. Participants had no history of neurological disorders and were required to have completed the equivalent education of high school. Language dominance was assessed through a functional transcranial doppler technique and a word generated task. An intracarotid amobarbital injection and fMRI were used in order to validate the previous aforementioned task. Participants were presented with a letter on a screen and were asked to generate as many words as possible with the target letter. Changes in the cerebral blood flow were measured throughout the task in order to assess the increase of metabolic activity in the brain. **Results:** The distribution of language lateralization was bimodal with approximately 1 in 13 healthy right-handed subjects being language dominant in the right hemisphere. **Conclusion:** While, the link between handedness and language dominance is not absolute, the relatively low number of right handed individuals with right hemisphere language dominance is an exception. **Relevance to the current work:** All participants in the current study were required to be right handed.


**Objective:** This paper overviews the mismatch negativity (MMN) and what it reflects in a research setting. **Conclusion:** To appropriately assess hearing it is essential to consider the functionality of brain as well as the ear. Auditory function can be assessed through the use of surface evoked potentials which can be elicited at all levels of the auditory system. The MMN is an evoked potential that occurs when there is deviance in repetitive auditory stimuli. Therefore, the MMN can be used for determining discrimination abilities when assessing auditory processing. Furthermore, the MMN is sensitive to changes in stimuli at the psychophysical discrimination threshold and is a pre-attentive response. The MMN typically occurs about 200ms after a deviant stimulus is presented. The MMN can be influenced by changes in spatial and phonemic changes, frequency, intensity, and duration. The MMN is obtained by using an “oddball paradigm.” Synthesized speech is an important element in obtaining the MMN because
of its sensitivity to small changes. Stimuli pairs that were used in testing included /da/-/ga/, /ba/-
/wa/, and /da/-/ta/. A control procedure used to obtain the MMN included reversing the roles of
the stimulus pair. The MMN is robust in assessing both children and adults. Relevance to current
work: This paper outlines the fundamental components of finding and interpreting the MMN in a
clinical and research environment.

related potential elicited by speech stimuli. Ear and Hearing, 13,158-164. doi:
10.1097/00003446-199206000-00004

Objective: The authors designed this study in order to investigate the mismatch negativity
(MMN) in adults and school-age children in order to determine if it could be a robust measure
for assessing central auditory function. Methods: Participants included 10 young adults between
the ages of 17 and 29 and 10 children between the ages of seven and 11. All participants had
normal hearing and were in good health. The synthesized phonemes /da/ and /ga/ were presented
using the “oddball” paradigm at 75dB SPL through insert earphones. Throughout presentation of
the speech stimuli, participants watched a visual stimulus (videotapes or cartoons) in order to
control the level of arousal and minimize participants awareness to the test stimuli. Electrodes
were placed on the participants head and Fz/A2 were used to record the MMN with the forehead
as ground. Results: Results determined that the MMN was present in all participants tested. The
presence of the MMN suggests that it can be elicited across different stimuli and age ranges.
Conclusions: The MMN is robust enough to be used diagnostically across adults and school age
children. Furthermore, the absence of or abnormalities in the MMN could be indicative of a
pathology. Relevance to the current work: This study suggests that the MMN is robust enough to
be used diagnostically and therefore can also be used as a research tool for assessing variation
amongst populations.

Dissociation between the activity of the right middle frontal gyrus and the middle
temporal gyrus in processing semantic priming. PLoS ONE, 6, e22368.
doi:10.1371/journal.pone.0022368

Objective: The authors sought to determine if the right middle frontal gyrus and the middle
temporal gyrus showed different sensitivity when priming occurred. Methods: Participants
included 20 right handed English speakers who aged from 19 to 39 years of age. Participants
were presented with spoken words, which employed an oddball paradigm, while performing a
silent counting task. Participants completed six runs of the task and each lasted approximately 9
minutes. Brain imaging was completed following presentations. Results: The results of the study
showed that the right middle frontal gyrus was sensitive to the relationship between the prime
and target of categorical relations. Furthermore, deactivations in the middle frontal gyrus
represented interactions of semantic overlap and condition. Conclusion: This study concluded a
dissociated in activity between the right middle frontal gyrus and the middle temporal gyrus
bilaterally as a result of semantic overlap on repetition priming. Relevance to the current work:
This study suggests that priming may influence the reaction of different parts of the brain. The
repetitive nature of the current research may be influenced by priming.
Objective: This text discusses the changes that occur in the auditory processing system as individuals age. The text supports the idea that elderly adults may be able to hear the speech sounds, but they may have difficulty understanding what is being said in demanding listening conditions. The text reviews age-related changes in the peripheral, central-auditory, and cognitive systems, the relationship between the decline in speech perception and hearing sensitivity, and the implication for rehabilitation in older adults. Relevance to the current work: The information in this text provides invaluable information for understanding how speech understanding is influenced in the older adult population.


Objective: This study aimed at studying the prevalence and source of hearing loss in adults 70 years and older. Methods: The National Health and Nutritional Examination Survey was used as a means of surveying multiple populations. Participants received an audiometric examination according to a modified Hughson Westlake procedure. Results regarding the hearing loss were categorized based on the American Speech-Language Hearing Association guidelines. Conclusion: The prevalence of hearing loss in adults older than 70 years old was approximately 63.1%. Furthermore, the African American race is less likely to suffer from age related hearing loss. Also, hearing aid use and the severity of the hearing loss is related. Relevance to the current work: This study provides an appropriate estimate of the prevalence of hearing loss within the geriatric population. Furthermore, this study provides information regarding external factors that could influence hearing loss.

Na, W., Kim, G., Kim, G., Han, W., & Kim, J. (2017). Effects of hearing loss on speech recognition under distracting conditions and working memory in the elderly. Clinical Interventions in Aging, 12, 1175-1181. doi:10.2147/CIA.S142962

Objective: This study aimed at exploring the relationship between communication difficulties and the severity of hearing loss in older adults. This study explored the impact that speech in noise, fast-rate speech, and working memory had on individuals with hearing loss. Methods: Participants were administered the Mini Mental State Exam and reported no ear surgery or age-related chronic disease. Participants underwent tympanometry and pure-tone audiometry testing and were separated according to the severity of their hearing loss. Patients were tested for speech perception in quiet, noisy, and very noisy environment. Furthermore, they were also tested for speech perception in normal, slightly fast, and fast rate of speech environments. Understanding and working memory was assessed by the patient's ability to repeat the test stimuli. Results: The research found that as environments became noisy and speech increased in speed, speech perception scores decreased. Conclusion: The presence of noise led to a steep decrease in speech perception. Compression of rate and working memory tasks led to a modest decline in speech perception. Relevance to the current work: This study supports the idea that age-related hearing
difficulty is a result of changes in peripheral and central auditory processing and cognitive performance.


*Objective:* This paper outlined previous research regarding the mismatch negativity (MMN) event-related potential. Specifically, the relationship between the MMN and both healthy and pathological central auditory function. The author describes how the MMN is elicited through the use of an oddball paradigm. Additionally, this paper outlines the relationship between the MMN and how it can be an indicator of neurophysiological processes associated with hearing loss. The author also outlines the specific dipoles and locations within the auditory cortex that may influence the presence of the MMN response. *Relevance to the current work:* The information regarding the components and indicators of the MMN are invaluable in determining its role in auditory function.


*Objective:* This paper outlined the previous research regarding the mismatch negativity (MMN) that has been presented in the previous 30 years. This paper outlined when the MMN is known to occur and what circumstances provide the best setting for the MMN to be observed. The MMN is dependent on the presence of short-term memory and is influenced by the likelihood of a deviant stimulus. Additionally, the MMN is not dependent on attention, and will increase in intensity as the magnitude of the stimulus changes. This paper also reinforces the knowledge that the MMN can be elicited through variations in speech sounds and can potentially influence higher-order language processing. *Relevance to the current work:* The strength of this paper lies in its information regarding previous research associated with the MMN.


*Objective:* This paper explores the effects of age on speech perception. Particularly how age-related changes in speech perception can lead to difficulty with audibility, temporal processing, and complex task processing. In terms of audibility, the paper state that as age increases threshold elevation may account for changes in speech perception. In regards to complex tasks and temporal processing, older adults appear to have difficulty understanding speech in noisy and fast pace environments. *Conclusion:* This paper emphasizes the relationship between speech perception and the aging population. *Relevance to the current work:* The current study explores the relationship between speech perception and aging.

Objective: E-prime 3.0 aids in transferring visual and auditory stimuli from the computer to the participant. Relevance to current work: E-prime 3.0 was used in the current study during stimulus presentation.


Objective: The authors designed this study in order to compare the P300 during an active and a passive stimulus. Also, the study was designed to analyze the age dynamics in the P300 between voluntary and involuntary attention and to assess the possibility of using evoked brain potentials to identify children who may be at risk for learning disabilities. Methods: Participants included 57 school age children between the ages of seven and 17 who had no history of cognitive impairment or neurological pathologies. Participants were divided into three groups according to their age. Electrodes were placed on each child and baseline Electroencephalography (EEG) data was recorded. Following collection of baseline data, each participant was presented with 100 tonal stimuli, 200 tonal stimuli, or 100 tonal stimuli at either 1000 Hz or 2000 Hz and was instructed to count the number of deviant stimuli. Evoked potentials were recorded while participants closed their eye and were presented with the stimuli. Results: Results determine that the waveform was similar across all the age groups tested. However, the P300 wave had a lower amplitude and longer latency in the youngest age group. Furthermore, differences in evoked potentials were seen in passive and active perception across all participants. Conclusion: There are differences across ages in relation to the latency of the p300. Furthermore, passive and active stimuli will both result in the observance of evoked potentials. Relevance to the current work: Active and passive manners of response can be used in data collection. Furthermore, there is a difference across age ranges about the brain’s way of processing stimuli.


Objective: The purpose of this study was to establish a link between the perception of native and nonnative phonetic categories through the use of behavioral and electrophysiological responses. Methods: Participants included 10 native Hindi speakers who had spent at least the first 20 years of life in India and 10 native American-English speakers who had no experience with the Hindi language. Initially, participants were presented with the phonemes /ba/ or /pa/ that displayed slight /r/ coloration at the conclusion of the phoneme and that had varying voice onset times (-50 and -10). Participants were asked to identify the phonemes as same or different. Following distinguishing between the two phonemes, participants were then asked to watch a video tape while the stimuli were presented into the right ear. Results: Hindi listeners identified voice onset times of 0 and -20 for the phoneme /pa/ and -50 and -90 for the phoneme /ba/; however, English speakers identified all stimuli as the phoneme /ba/. Furthermore, Hindi speakers displayed a more robust MMN when distinguishing the difference between the phonemes /ba/ and /pa/ when compared to English speakers. Conclusion: The lack of strength in the MMN for the American English population suggests that the MMN is housed in a language specific level of the brain.
Relevance to the current work: This study provides insight into where the MMN originates in the brain. Furthermore, this study emphasizes the influence that language experience can have on the MMN; therefore, participants were required to be native English speakers in order to participate in the current study.


Objective: This study sought to determine the effects of stimulus intensity on the latencies of evoked potentials. Methods: Participants included six healthy male volunteers. Participants were instructed to remain in a quiet room and to relax their eyes. Electrodes were placed on participants and electrical data was recorded. Stimulus intensities were varied by thresholds of 1.5, 2, 2.5, 3, 3.5, 4, and 5. Results: The research found that the increase in intensity influenced the start latency of the participants. Minimal changes were found in peak latency and end latency. Conclusion: Increased intensity of 2-3 times may influence the latency of participants. Relevance to the current work: The close relationship between event-related potentials and evoked potentials suggest that the influence of intensity on evoked potentials may also influence event potentials. Therefore, this study poses a limitation to the current research.


Objective: This text provides information regarding previous studies and their contribution to speech perception related to aging. This study explores the cognitive abilities, lexical discrimination abilities, and talker differences in the geriatric population. Conclusion: Attempts to corelate cognitive abilities with speech perception have been met with speculation. Cognitive abilities research has often focused on the two subcategories of intelligence and memory and has not tested further cognitive functions. Furthermore, cognitive functioning tests had not provided a naturalistic look at how speech is processed. Additionally, older individuals have been shown to have difficulty understanding talker differences, or the changes in acoustic variation from person to person. The study further states that the lexical density of words can lead to an increase or decrease in speech perception. Relevance to the current work: Knowledge about previous research in the area of speech perception is essential to the understanding of speech perception in older adults.


Objective: This paper sought to explore the influence of Broadmann Areas. Specifically, this study identifies the core functions of specific Broadmann Areas. Conclusion: This paper establishes the validity of using Broadmann Areas for source identification. Relevance to the current work: The current study utilized Broadmann Areas for source localization.
Objective: Trans Cranial Technologies publishes a cortical functions reference guide that helps in the localization of specific Brodmann areas, as they relate to the 10-20 system. This guide aids in the localization and functioning of Brodmann areas as they to EEG cap placement. 

Relevance to the current work: The present study utilized the cortical functions reference for localization and determination of the functioning of cortical areas of activation within the study.