GENDER AND EAR INFLUENCES ON THE SPEECH-EVOKED MIDDLE LATENCY RESPONSE (MLR)

By

Holden Daniel-Vernon Sanders

Audiology Doctoral Project Submitted to the Faculty of the

DEPARTMENT OF SPEECH, LANGUAGE, AND HEARING SCIENCES

In Partial Fulfillment of the Requirements

For the Degree of

DOCTOR OF AUDIOLOGY

In the Graduate College

THE UNIVERSITY OF ARIZONA

2019

THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

As members of the Audiology Doctoral Project Committee, we certify that we have read the Audiology Doctoral Project prepared by Holden Daniel-Vernon Sanders, titled *Gender and Ear Influences on the Speech-Evoked Middle Latency Response* and recommend that it be accepted as fulfilling the Audiology Doctoral Project requirement for the Degree of Doctor of Audiology.

Barbara Cone Date: 03/25/2019
Barbara Cone, Ph.D.

Nicole Marrone Date: 03/25/2019
Nicole Marrone, Ph.D.

Date: 03/25/2019
David Velenovsky, Ph.D.

Date: 03/25/2019
Christopher Johnson, Ph.D.

Final approval and acceptance of this document is contingent upon the candidate's submission of the final copies of the document to the Graduate College.

I hereby certify that I have read this audiology doctoral project document prepared under my direction and recommend that it be accepted as fulfilling the audiology doctoral project requirement.

Barbara Cone Date: 3-25-2019

Audiology Doctoral Project Chair: Barbara Cone, Ph.D.

ACKNOWLEDGEMENTS

I would like to especially thank Barbara Cone, Ph.D., who served as my research mentor for more than five years. I began working in her research lab, Arizona Human Electrophysiology and Auditory Development (AHEAD) Lab as an undergraduate at the University of Arizona. She is very passionate about electrophysiology and its potential in the field of audiology and has successfully passed on that passion to me. Not only has she mentored me with respect to academics and research, but also worked with me on a personal level to become more confident in my skills and capabilities as a researcher and as an academic. Most of all, I appreciate how she has always, even as an undergraduate student, treated me as a budding researcher who is smart enough and capable of answering and engaging in important and complex questions about auditory processes and development.

I would also like to thank Spencer Smith, Au.D./Ph.D. I began to work with Dr. Smith as an undergraduate when he was working towards his Ph.D. in Audiology. Dr. Smith also mentored me in the research lab. I would go to him with large and small questions about the auditory system and electrophysiology. He would help me and try to answer my questions with little or no judgment. Additionally, this work would not have been possible without his indispensable assistance. I began recording middle latency responses before I fully understood what they were. The only way this was possible was with Dr. Smith's help in choosing the correct recording parameters, filters, and electrode setup.

This research first began the summer of 2013 when I participated in the Undergraduate Research Opportunities Consortium (UROC) in the Minority Health Disparities (MHD) program provided through the University of Arizona Graduate College. This program encouraged me to pose on pursue my own research questions, in addition to providing me funding to begin this research project and provide educational resources to help me get into graduate school and specifically the Audiology in the Speech, Language, and Hearing Sciences department at the University of Arizona.

TABLE OF CONTENTS

Abstract

Auditory evoked potentials (AEP) are used to evaluate auditory system function from the level of the auditory nerve to the auditory cortex and association areas. For auditory evoked potentials to reach their full power as an assay of hearing and brain function, it is important to understand stimulus- and subject-related variables. The middle latency response (MLR) is one type of auditory evoked potential that reflects the activity of the auditory nervous system at levels including the auditory thalamus and primary auditory cortex. Whereas gender and laterality-related differences have been found at the level of the inner ear and brainstem, limited studies have investigated gender differences at the level of the auditory thalamus and primary auditory cortex. Additionally, the use of complex stimuli, such as a consonant-vowel token, and presentation of stimuli in noise has been investigated for other evoked potentials, but few studies have used this type of stimulus to elicit the MLR. Therefore, the current study was undertaken to evaluate the effect of gender and laterality (ear) differences (subject-related parameters), and stimulus complexity and masking (stimulus-related parameters), on the MLR. Gender differences were found in the current study, revealing shorter MLR component latencies and larger amplitudes in females compared to males. No ear-related differences were evident, however. The speech token /da/ was effective in evoking an MLR that displayed latency and amplitude characteristics like those found in studies that used click or tone-burst stimuli. Contralateral masking noise resulted in reduction of the MLR amplitude, which is the classical definition of suppression with respect to this specific AEP. This study clearly establishes gender as a significant subject-related parameter, and the use of complex stimulus paradigms that can be applied to clinical applications of MLR.

Introduction

The MLR is a type of auditory evoked potential (AEP) (Müller, Keil, Kissler, & Gruber, 2001; Picton, 2011). It results from the same raw electroencephalogram (EEG) as the auditory brainstem response (ABR), but focuses on a different point in time and different anatomical correlates. The MLR occurs within the first 10 to 80 ms following auditory stimulation (Picton, 2011). Its neural generators are thought to be the auditory thalamus, primarily medial geniculate body, and primary auditory cortex, also known as Heschl's gyrus, or the belt region of the superior temporal gyrus. The main components of the MLR are Pa, Nb, and Pb. Wave Pa occurs between 25 and 35 ms, Nb 35 to 45 ms, and Pb at 50 to 80 ms (Jerger, Oliver, & Chmiel, 1988) (Figure 1).

Like an ABR, the MLR is stimulus-dependent, which means that the wave characteristics, latency, amplitude, and inter-peak intervals are affected by characteristics of the auditory stimulus eliciting the response such as: frequency, rate, duration, and rise-time. There are also subject-related parameters that can affect the MLR, such as state-dependencies.

The MLR is known to vary systematically with stimulus parameters such as frequency, rate, and level (Picton, 2011), but limited studies have characterized the speech-evoked MLR (J. M. Anderson, 2011). One aim of this study was to fill this knowledge gap by using a speech token to evoke the MLR and evaluate the effect of masking noise in conjunction with the speech token stimulus.

Stimulus duration and complexity are also important factors to consider for eliciting the MLR, as this measure represents more complex auditory processing than earlier responses in the central auditory nervous system (CANS), such as the ABR (Kraus & McGee, 1990). One example of a long-durations and complex stimulus that can be used to evoke an AEP is a speech token (Agung, Purdy, McMahon, & Newall, 2006). This stimulus type has an additional advantage in that it is the closest representation to speech that will evoke a synchronous response (Wible, Nicol, & Kraus, 2002). Representing speech is critical, as understanding speech is an important part of the human experience. Speech tokens have already been used to elicit the ABR (Krizman, Skoe, & Kraus, 2010, 2012; Kumar Neupane, Gururaj, Mehta, & Sinha, 2014; Lehmann & Schönwiesner, 2014), and late latency response (LLR) (Prakash, Abraham, Rajashekar, & Yerraguntla, 2016; Sharma, Kraus, McGee, & Nicol, 1997; Tremblay, Kraus, McGee, Ponton, & Otis, 2001). These studies imply that a speech token can be used at any level of the auditory system, especially since this type of stimulus has been used to elicit responses from neural generators at lower levels (i.e. ABR) and higher levels (i.e. LLR) than those of the MLR. Thus, it seems logical that the speech-evoked MLR should be no different.

In terms of subject-related parameters that could affect the MLR, gender (J. M. Anderson, 2011; Berninger, 2007; Don, Ponton, Eggermont, & Masuda, 1993; Kei, McPherson, Smyth, Latham, & Loscher, 1997; Keogh, 2001; Krizman et al., 2012; Liu, Wang, Li, Shi, & Wang, 2009; McFadden, 2002; Snihur & Hampson, 2011, 2012; Thornton, Marotta, & Kennedy, 2003; Tsolaki, Kosmidou, Hadjileontiadis, Kompatsiaris, & Tsolaki, 2015; Tucker, 2002) and ear (or laterality) differences (Berninger, 2007; Kei et al., 1997; Keogh, 2001; Liu et al., 2009; McFadden, Hsieh, Garcia-Sierra, & Champlin, 2010; Pavlovcinova et al., 2010; Thornton et al., 2003) are well-established in human audition. Gender and ear differences have been found at the level of the peripheral auditory system (Berninger, 2007; Pavlovcinova et al., 2010; Snihur & Hampson, 2011, 2012) and brainstem.

Studies have found gender differences at the level of the brainstem as measured with the ABR (Don et al., 1993). Females have been shown to have shorter wave V ABR latencies, by about 0.1 ms (Don et al., 1993), and larger amplitudes, approximately 30% greater, when compared to males. Larger amplitudes have also been found in the right ear compared to the left as measured at the brainstem with the ABR (McFadden et al., 2010). Similarly, Tucker et al. (2002) investigated the effect of stimulus rate and gender on the Middle Latency Response (MLR) in response to a click stimulus (Tucker, 2002). The investigators found a significant effect of gender on Pa latency and amplitude, where Pa latencies were longer in males and Pa amplitudes were larger in females. However, another study investigating gender differences in the MLR elicited by a click did not find significant differences for the presence of an MLR between male and female children (Kraus, Smith, Reed, Stein, & Cartee, 1985). They also did not find differences between left and right ears. This possibly points to a disparity between the effect of gender on different auditory evoked potentials and various measures of these potentials. For example, spontaneous otoacoustic emissions (SOAEs) are present more often in females compared to males (McFadden & Pasanen, 1999), but this does not hold true for the presence of the MLR (Kraus et al., 1985).

Another important subject-related parameter to consider is ear or laterality differences. Ear differences have been found in OAEs (Keefe, Gorga, Jesteadt, & Smith, 2008; McFadden, 1993; McFadden, 1998; McFadden et al., 2010) and even as an interactive factor alongside gender and sexual orientation (McFadden, 1993; McFadden et al., 2010). Ear differences have been identified in the ABR (Keefe et al., 2008; Sininger & Cone-Wesson, 2006) and at the level of the MLR/40-Hz ASSR in a limited number of studies (Ross, Herdman, & Pantev, 2005; Weihing & Musiek, 2014; Weihing, Schochat, & Musiek, 2012). Ear differences are important to determine how much differences in the earlier AEPs of the CANS contribute to a right-ear advantage (Haggard & Parkinson, 1971; Porter & Berlin, 1975; Shankweiler & Studdert-

Kennedy, 1967) and how to interpret differences between ears when assessing central auditory function (Musiek, Baran, & Pinheiro, 1992; Roth et al., 1980).

Suppression

Suppression reflects the activation of the medial olivary cochlear (MOC) reflex and auditory efferents (de Boer, Thornton, & Krumbholz, 2012; Garinis, Glattke, & Cone, 2011; Giraud et al., 1997; Matas, Silva, Leite, & Samelli, 2010). Suppression is measured as the difference in amplitude or latency of auditory evoked potentials (AEPs) between two conditions, quiet and with contralateral noise. Activation of the MOC in the presence of noise is thought to play a role in speech understanding in noise (Giraud et al., 1997), although, some studies have found no correlation between suppression/inhibition and speech understanding in noise (Garinis, Werner, & Abdala, 2011; Scharf, Magnan, & Chays, 1997; Wagner, Frey, Heppelmann, Plontke, & Zenner, 2008). Thus, the role of suppression/inhibition is still up for debate. One hypothesis is that suppression of auditory evoked potentials correlates with increased attention and speech understanding in noise (de Boer et al., 2012; Giraud et al., 1997). Suppression effects appear to differ with age: older (> 41 years old) individuals have been shown to have smaller amplitudes and a longer inter-wave interval (Lavoie, Mehta, & Thornton, 2008). Even though the role of suppression of AEPs in speech-in-noise understanding is still controversial, suppression has been shown to result from the central auditory nervous system efferents and not a byproduct of the acoustic reflex (Harkrider & Smith, 2005).

Gender differences in suppression have been observed in otoacoustic emissions (OAEs) (Berlin, Hood, Hurley, Wen, & Kemp, 1995; Durante & Carvallo, 2002; McFadden, 1993) and the auditory brainstem response (ABR) (Elkind-Hirsch, Wallace, Malinak, & Jerger, 1994;

Sininger & Cone-Wesson, 2006). Effects of contralateral suppression of the MLR have also been found, but gender differences in the suppression of the MLR have yet to be investigated (Ozdamar & Bohórquez, 2008).

Purpose

Gender effects and the speech-evoked middle latency response (MLR) have not previously been investigated. The aim of this study was to investigate gender differences and characterize the speech-evoked MLR. Firstly, the main objective of the study was to determine if gender and/or ear differences exist in the speech-evoked MLR. The second main purpose was to characterize the speech-evoked MLR with respect to the effects of noise and whether suppression effects and release from suppression effects are evident.

Questions and Hypotheses

The purpose of this study was to experimentally investigate three main questions: 1) Are gender differences seen in the speech-evoked middle latency response? 2) How do different noise conditions affect the amplitudes and latencies in the speech-evoked middle latency response? Specifically, is contralateral suppression evident in the speech-evoked MLR with the introduction of contralateral, low-level white noise? Is release from suppression also evident when presenting noise bilaterally? 3) Are ear differences evident in the speech-evoked MLR?

The hypotheses proceeding this study were: 1) females will have shorter latencies compared to males, 2) females will have larger amplitudes compared to males, 3) suppression with the introduction of noise will be evident, 4) release from suppression will be apparent. 5) there will be differences between ears, and 6) differences between ears will be related to handedness.

Methods

Subjects

Forty-five subjects were recruited for the study, all but one of which were college age, (18-24 years). Participants were recruited from the university using convenience sampling. To be included, participants had to pass otoscopy and a hearing screening, have acoustic reflexes at 70 dB SPL or greater for a broadband noise stimulus (Guinan, 2006), and confirm that they were healthy enough to qualify to participate in the research study. Otoscopy was considered a pass if eardrums were visible and no perforations, redness, bulging, or drainage were observed. To pass the hearing screening, participants had to respond to pulsed pure tones at 20 dBHL for frequencies 1000-6000 Hz and at 25 dBHL for 500 Hz. Thresholds 25 dBHL or greater are considered to be abnormal and evidence of hearing loss (Clark, 1981). For most frequencies, 20 dBHL is used as a conservative criterion. However, 500 Hz is more susceptible to environmental masking, so the criteria of 25 dBHL is used instead. Additionally, pure-tone thresholds are in good agreement with those estimated using MLR (Kankkunen & Rosenhall, 1985), and so appropriate for eliminating participants from the study with a hearing loss at all or some frequencies who would likely not have a normal MLR.

Two participants were excluded because they did not pass the hearing screening. Four participants did not qualify for the study because they had acoustic reflexes below 70 dB SPL. Participants were also excluded if their MLR recordings did not meet low-noise criteria within a 2-hour recording period. Eight participants were excluded on this basis. One participant removed themselves from the study, because they indicated that they did not qualify for the study based on the experimental criteria. Two other participants did not return for the second half of the experiment and one participant was excluded because they did not have discernable right waveforms, so data from these three participants were not included in the analysis. In total, data from twenty-seven subjects were included in the study, 14 females and 13 males.

Handedness

In addition to the measures above, participants also completed a handedness questionnaire to see if handedness influenced ear differences, if present, as differences due to handedness have previously been found in the MLR (Mohebbi et al., 2014). Participants were asked to read ten items from the modified Edinburgh Handedness Inventory (mEHI) and indicate with a plus (+) whether they performed the task with their right hand, left hand, or both (Dragovic, 2004; Milenkovic & Dragovic, 2013). Items included: ‘writing’, ‘drawing’, ‘throwing’, ‘scissors’, ‘toothbrush’, ‘knife’, ‘spoon’, ‘broom’, ‘matches’, ‘opening box-lid’. A laterality quotient was then calculated from the responses by summing the number of responses for the right hand (RH) and the number of responses for the left hand (LH), then calculating the quotient with the equation $LQ = [(RH – LH)/(RH + LH)] \times 100$ (Dragovic, 2004). A score of 60 or greater strongly indicated a preference for using the right hand and a score of -60 or less strongly indicated a preference for the left hand (Milenkovic & Dragovic, 2013). No participants were excluded based on LQs. The average LQ was 54.46 suggesting that most participants were right-handed. Additionally, only seven participants had LQs, trending towards left dominance, only one of which was considered significant at -75 (Kreutzer, DeLuca, & Caplan, 2011). All other subjects (20) had LQs that trended towards right handedness, 15 of which were significant.

Stimuli

All stimuli used were generated with the Intelligent Hearing Systems SMART-EP (IHS) system. The speech token, /da/, had a 40 ms duration (Krizman et al., 2010) and was presented at 60 dBA SPL at a rate of 11.7/s. White noise was presented at 65 dB dBA SPL as the contralateral stimulus. Ipsilateral noise was also white noise presented at 50 and 40 dBA SPL for 10 and 20 dB signal-to-noise-ratio (SNR) conditions respectively. All stimuli were calibrated using the Larsen Davis System 824 Sound Pressure Level (SPL) Meter. Output from ER-3A headphones were configured with a 2cc coupler and steady-state root-mean-squared (RMS) SPL of the stimuli were measured.

MLR Recording Parameters

MLRs were recorded using a 6-channel montage. The channels were: Cz-Ai, Cz-Ac, C3-Ai, C3-Ac, C4-Ai, C4-Ac. An electrode located on the forehead served as the ground. The EEG was filtered from 10-1500 Hz and amplified with a gain of 100 dB. The evoked potentials were averaged using an epoch of 76.8 ms. The amplitude-based artifact reject-criteria was set to reject recordings greater than 20 µV. Each waveform comprised two 2000 artifact-free averages for a total of 4000 samples. Two-thousand sweeps were made for each accepted recording to eliminate as much myogenic noise as possible. Averaging two different recordings for the total 4000 sweeps, further eliminated noise that would not be attributed to the anatomical generators of the MLR.

Procedure

Two test sessions were required to obtain MLRs for right and left ears for all stimulus and noise conditions. Subjects' left and right ears were recorded on separate days except for one participant whose right and left ears were tested on the same day. There was an average 26.8-day interval between recording sessions. Four individuals had testing intervals greater than 60 days.

The order of ear and noise conditions were randomized across subjects, which included two runs per condition and ear. The experimental conditions included a) Quiet—speech stimuli only, b) Ipsilateral 10 dB SNR—speech stimuli and noise in the same ear at 10 dB SNR, c) Ipsilateral 20 dB SNR—speech stimuli and noise in the same ear at 20 dB SNR, d) Contralateral—speech stimuli and noise in opposite ears, e) Contralateral/Ipsilateral 10 dB SNR—noise in both ears with speech stimuli and noise in one ear at 10 dB SNR, and f) Contralateral/Ipsilateral 20 dB SNR—noise in both ears with speech stimuli and noise in the other ear at 20 dB SNR.

Participants sat in a reclining chair and were asked to preoccupy themselves with something on their phone/tablet or read a book for enjoyment in order to ensure that they remained awake for the recording and asked to move as little as possible. Participants were able to take a break whenever they requested and were offered a break halfway through the recordings.

Data Analysis

Waveform data from the IHS system was saved in ASCII files, which were uploaded to Igor Pro to compare raw waveforms. ABR and MLR components of individual waveforms to be included were marked, saved into PDF format, then manually entered into Excel. The lead investigator (HS), trained by the principle investigator (BC) marked all subject waves using a rule-governed procedure to identify the most likely ABR and MLR peaks and troughs without referencing subject information. Peak latency was measured at the most prominent peak or trough for a given component within an expected time range (Picton, 2011). As peaks could sometimes be difficult to identify, either due to noise and/or the presence of a frequency following response (FFR), earlier or later components and components in other noise conditions were used as a reference as to where the peak was most likely to occur. If there was no discernable peak, then the peak latency was estimated, but given an amplitude of zero to indicate no peak. Amplitude was measured by taking the difference between V-V', Na-Pa, Pa-Nb, Nb-Pb, and Pb-N1.

Data from excel was arranged into a format consistent with Statview, then copied into Statview to be analyzed. First, descriptive statistics were generated. Prior to hypothesis testing with analyses of variance (ANOVA), correlations were performed to see if and which individual ABR/MLR components correlated with one another. Components that were correlated with respect to either latency or amplitude were analyzed together using a repeated measures ANOVA. With respect to latency, Na/Nb and Pa/Pb were found to be correlated respectively. As a result, negative latencies (Na/Nb) and positive latencies (Pa/Pb) were calculated together rather than as individual components. Alternatively, with respect to amplitude, Na/Pa and Nb/Pb were correlated, thus they were calculated together (i.e. Na with Pa and Nb with Pb). Significance for gender, ear, and condition were investigated using one and two-tailed ANOVAs. The significance level was set to $p<.05$.

Results

MLR to Speech Tokens in Quiet and Noise

Figure 1 shows a set of representative MLR waveforms obtained from an individual in each condition (see figure legend). As can be seen, wave V and Na were not discernable in all noise conditions. Additionally, many waves included an FFR (figure component G) to the sustained vowel portion of the speech token, which made it difficult at times to mark the Pa component.

Appendices A-J provides tables of all ABR and MLR component latencies and amplitudes divided by gender, ear and condition.

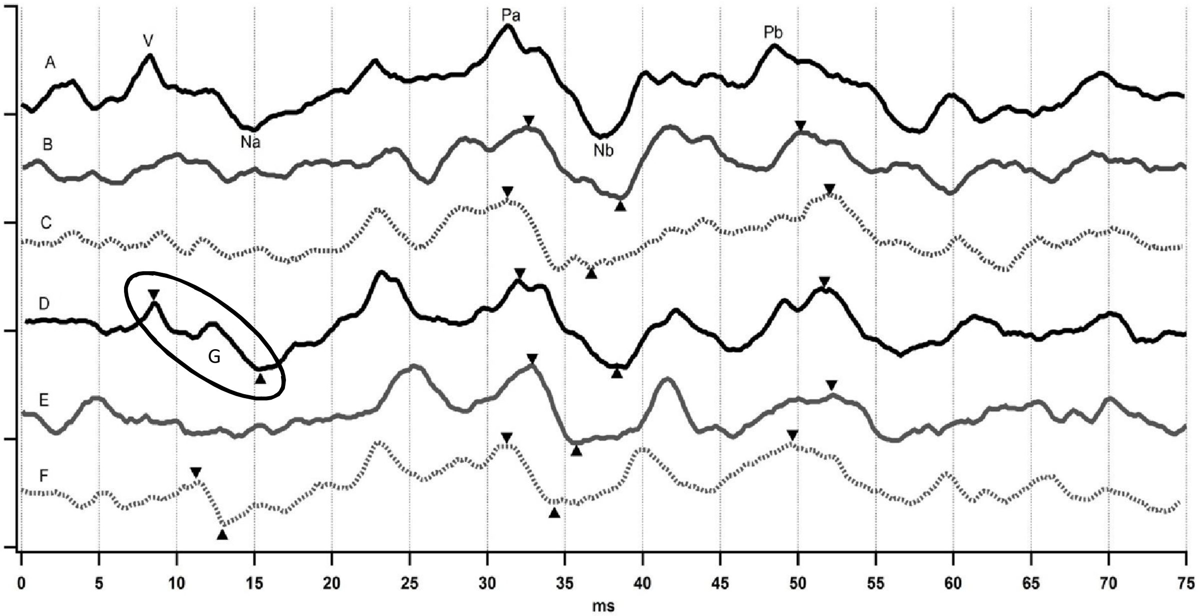


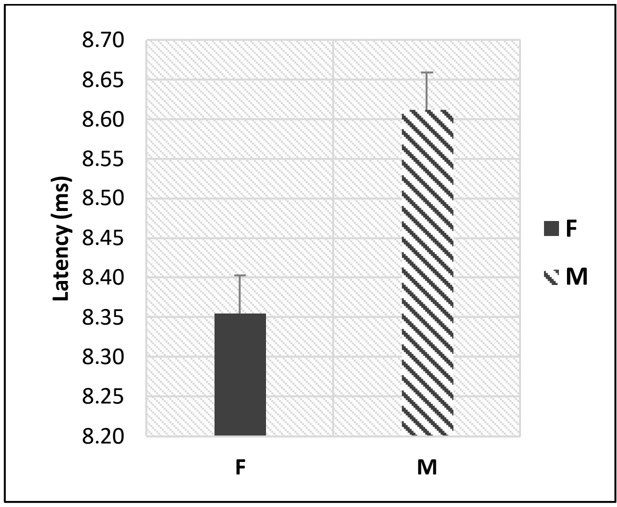
Figure 1. Waveforms from a representative subject (male, left ear) in response to the /da/token. ABR component wave V, and MLR components Na, Pa, Nb, and Pb are marked. Wave conditions are as follows: A) Quiet, B) Ipsi 10 dB SNR, C) Ipsi 20 dB SNR, D) Contralateral, E) Contra/Ipsi 10 dB SNR, and F) Contra/Ipsi 20 dB SNR. A frequency following response can also be seen in the contralateral waveform (G).

Gender Effects

The first question asked was whether gender effects exist in the speech-evoked ABR wave V and MLR components. Analyses of variance revealed that there were significant effects of gender on ABR wave V latency and amplitude (Table 1). These gender differences are illustrated in Figures 2a and 2b. Females had larger amplitudes and shorter latencies when compared to males, consistent with results found in studies using click-stimuli (Don et al., 1993).

Table 1. ANOVA ABR Component Latencies and Amplitudes

ANOVA Table for V Latency				ANOVA V Amplitude			
	DF	**F-Value**	**P-Value**		**DF**	**F-Value**	**P-Value**
Gender	1	15.643	<.002	**Gender**	1	3.877	<.058
Condition	5	10.889	<.001	**Condition**	5	21.756	<.0001
Residual	26			**Residual**	26		



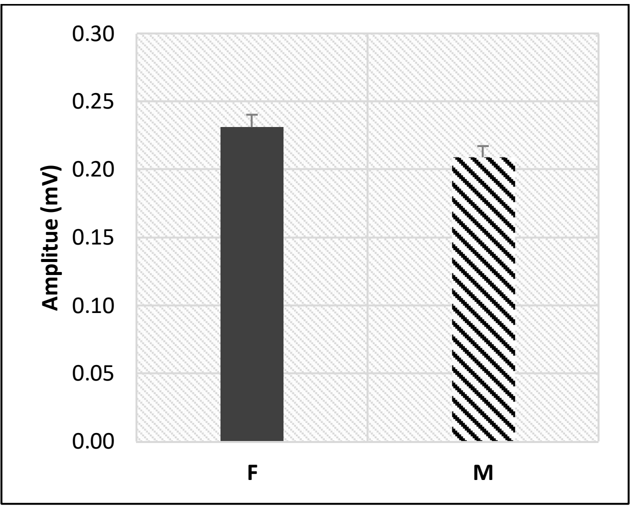


Figure 2a, 2b. ABR component, wave V latency (2a) and amplitude (2b). Latencies and amplitudes are averaged over ear (right and left) and noise conditions. Error bars indicate standard deviation.

Gender differences were also found for MLR components. Figure 3 graphs the latency differences as a function of gender. Females had significantly shorter latencies than males for MLR components Na, Pa, and Pb, but not for Nb. (Table 2). MLR component amplitudes showed a high correlation with one another (.040-0.76). For this reason, a repeated measures ANOVA was used. MLR amplitudes also showed a gender effect with females having larger amplitudes than males (Figure 4). However, there was a significant interaction between MLR-component and gender, because the Na-Pa amplitude was larger in males than females. The results of the repeated-measures ANOVA can be found in the Table 3.

Table 2. ANOVA MLR Component Latencies.

ANOVA Table for Pa Latency				ANOVA Table for Na Latency			
	DF	**F-Value**	**P-Value**		**DF**	**F-Value**	**P-Value**
Gender	1	48.457	<.0001	Gender	1	49.983	<.0001
Residual	26			Residual	26		

ANOVA Table for Pb Latency				ANOVA Table for Nb Latency			
	DF	**F-Value**	**P-Value**		**DF**	**F-Value**	**P-Value**
Gender	1	39.529	<.0001	Gender	1	.008	.9276
Residual	26			Residual	26		

Table 3. ANOVA MLR Amplitude

ANOVA MLR Amplitude (Total)			
	DF	**F-Value**	**P-Value**
Gender	1	24.294	<.0001
Condition	5	9.527	<.0001
Subject(Group)	26		

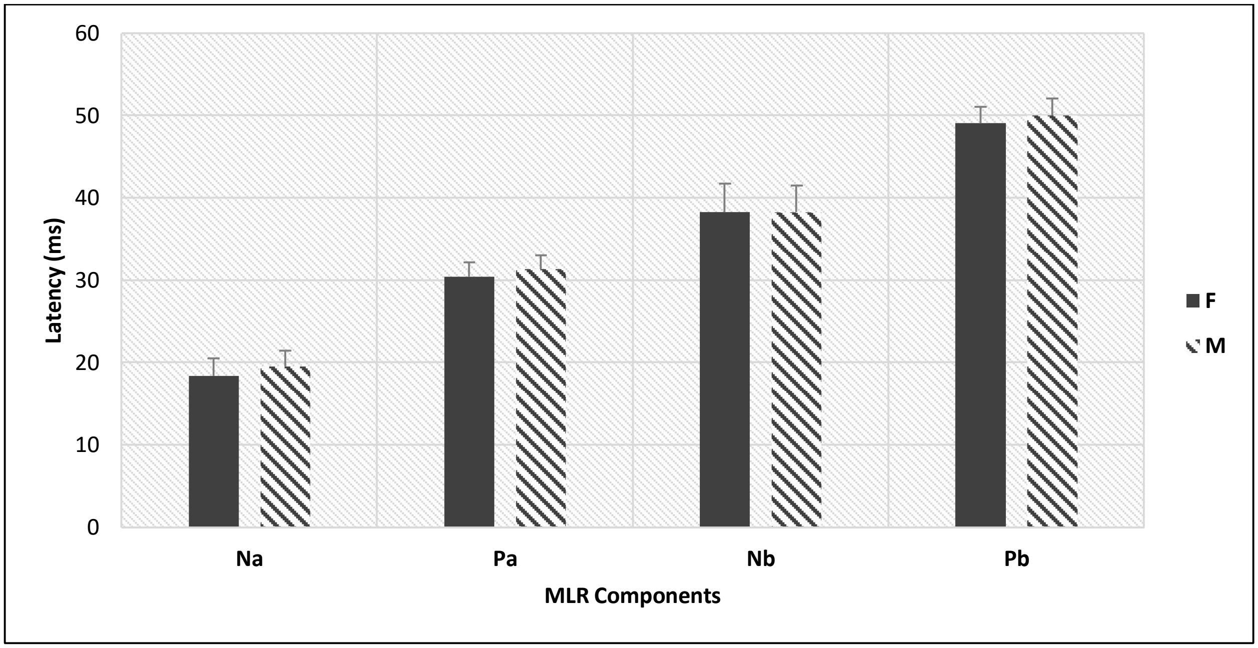


Figure 3. Average MLR component latencies. Latencies were significantly shorter for females, compared to males, for components Na, Pa, and Pb. No significant differences were found for component Nb. Error bars indicate standard deviation.

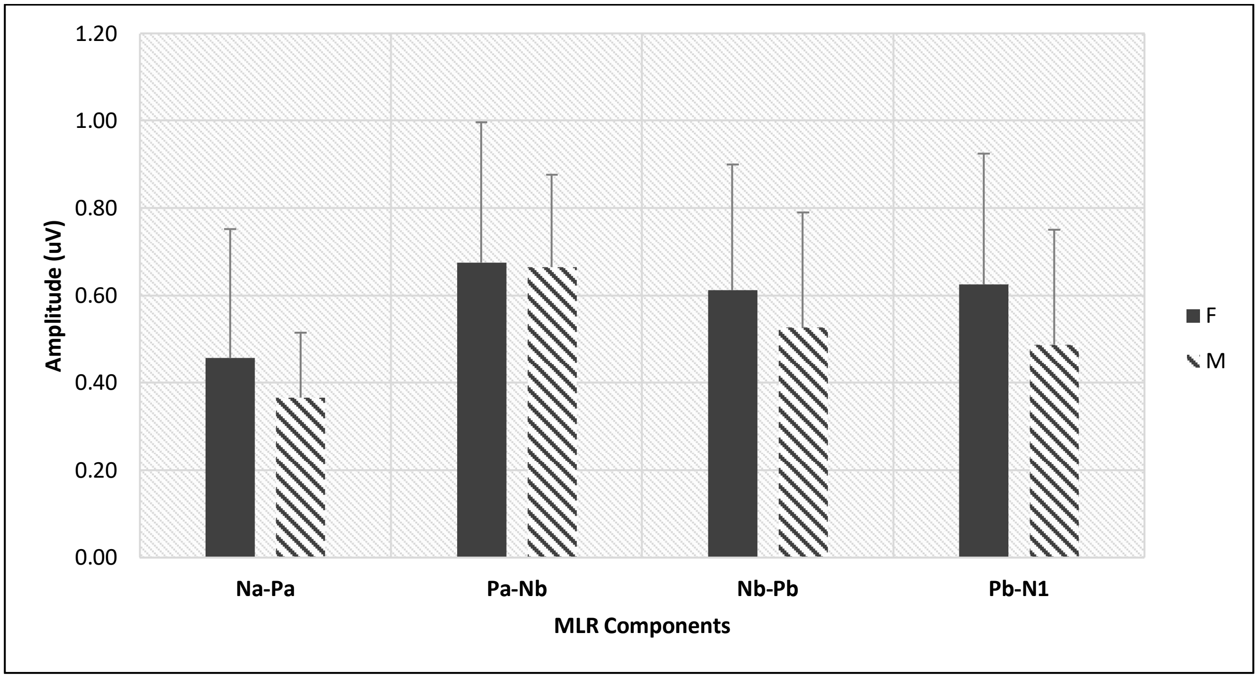


Figure 4. Average MLR component amplitudes for females and males. Error bars indicate standard deviation. Gender differences can be seen in amplitude with respect to gender, particularly with the Na and Pb components with amplitudes being larger in females when compared to males. Error bars indicate standard deviation.

Suppression

Suppression was defined as a change in amplitude or latency (compared with the quiet condition) with the introduction of contralateral noise at 65 dB SPL. There were no significant effects of contralateral noise on ABR or MLR component latencies. There was a decrement in ABR wave V-V’ and MLR component Pa-Nb amplitude when contralateral noise was introduced (Figure 5). There was, on average a 0.058-uV change in ABR and 0.109-uV change in MLR Pa-Nb. These amplitude decrements were significant for wave V and for MLR component Pa-Nb (Table 4).

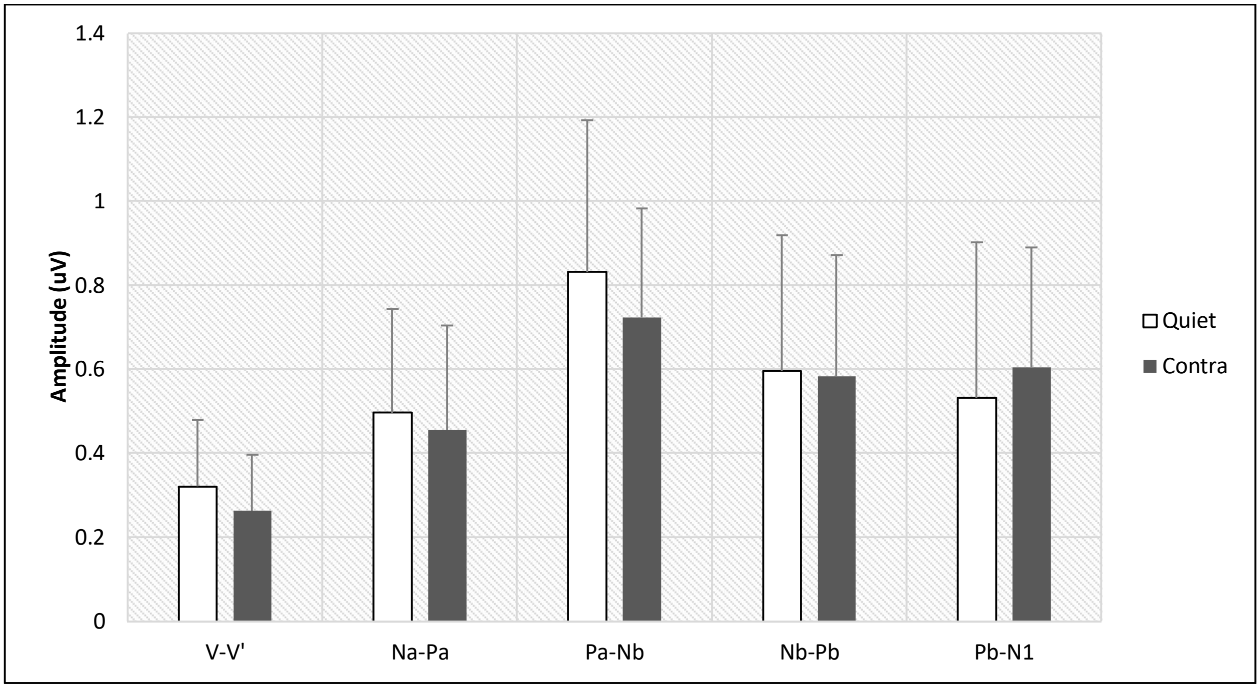


Figure 5. Amplitude differences for wave V, ABR component, and MLR components between the quiet and contralateral condition, averaged over all components, showing inhibition/suppression. Amplitudes are averaged across all subjects for each component. As can be seen by a reduction in amplitude between the quiet and contralateral conditions, suppression was evident in the ABR component (wave V) and for Pb. Error bars indicate standard deviation.

Table 4. ANOVA Contralateral Suppression V Amplitude

ANOVA Table for V Amplitude: Quiet and Contra				ANOVA Table for Pa Amplitude: Quiet and Contra			
	DF	F-Value	P-Value		DF	F-Value	P-Value
Condition	1	8.654	<.01	Condition	1	6.885	<.03
Residual	26			Residual	26		

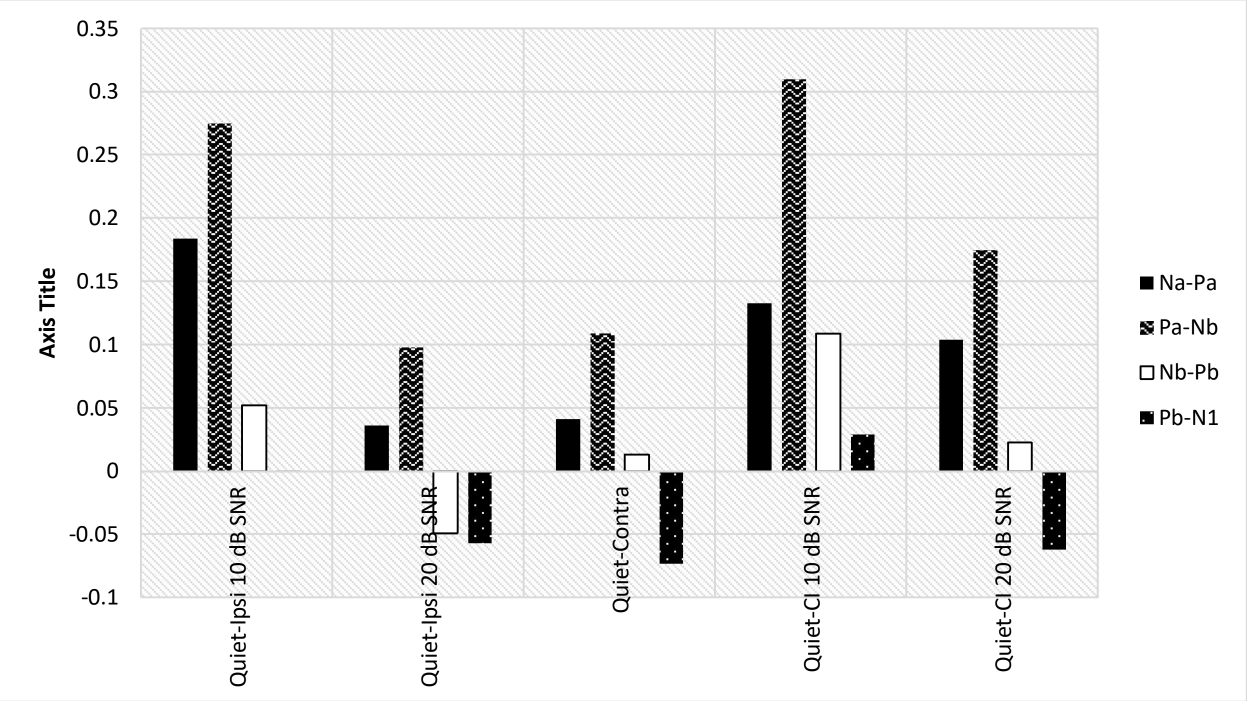


Figure 6. Plot of the difference between the quiet condition and five noise conditions. These differences are also broken down by component. Some differences show growth with the addition of noise, such as Nb-Pb for Ipsi 20 dB SNR and Pb-N1 for Ipsi 20 dB SNR, Contra, and Contra/Ipsi 20 dB SNR.

Noise Condition

In addition to evaluating the effects of contralateral noise for suppressive effects, the effects of ipsilateral noise at 10 and 20 dB SNR and contralateral noise presented with ipsilateral noise were measured. The results are illustrated in Figures 6, 7 and 8 and ANOVA results in Table 2. There were no statistically significant effects of noise condition on MLR component latencies (Figure 9). In general, the addition of noise, ipsilateral or contralateral, decreased amplitudes, with a greater reduction in amplitude in the presence of ipsilateral noise compared to contralateral noise, as well as with a lower signal-to-noise ratio (SNR) compared with a higher SNR. This is illustrated in Figure 7. The degree to which various noise conditions reduced amplitudes also varied based on component. For example, Na-Pa and Pa-Nb amplitude seemed to be most affected by noise condition, whereas Nb-Pb and Pb-N1 were the least affected (Figure 9). Lack of suppression with certain components, might represent a difference in how efferents function at the corresponding anatomical generators.

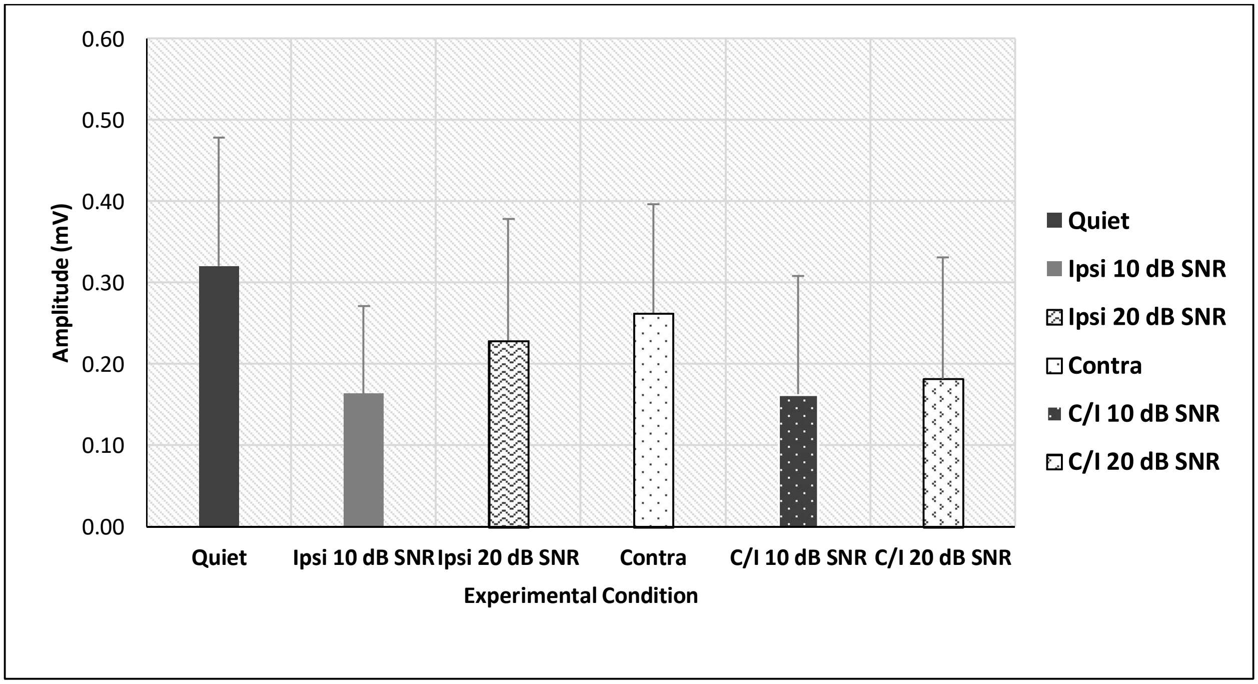


Figure 7. Amplitude changes as a function of condition, averaged over all peaks. As can be seen with the bar graphs, amplitude varies with differing noise condition for the speech-evoked MLR.

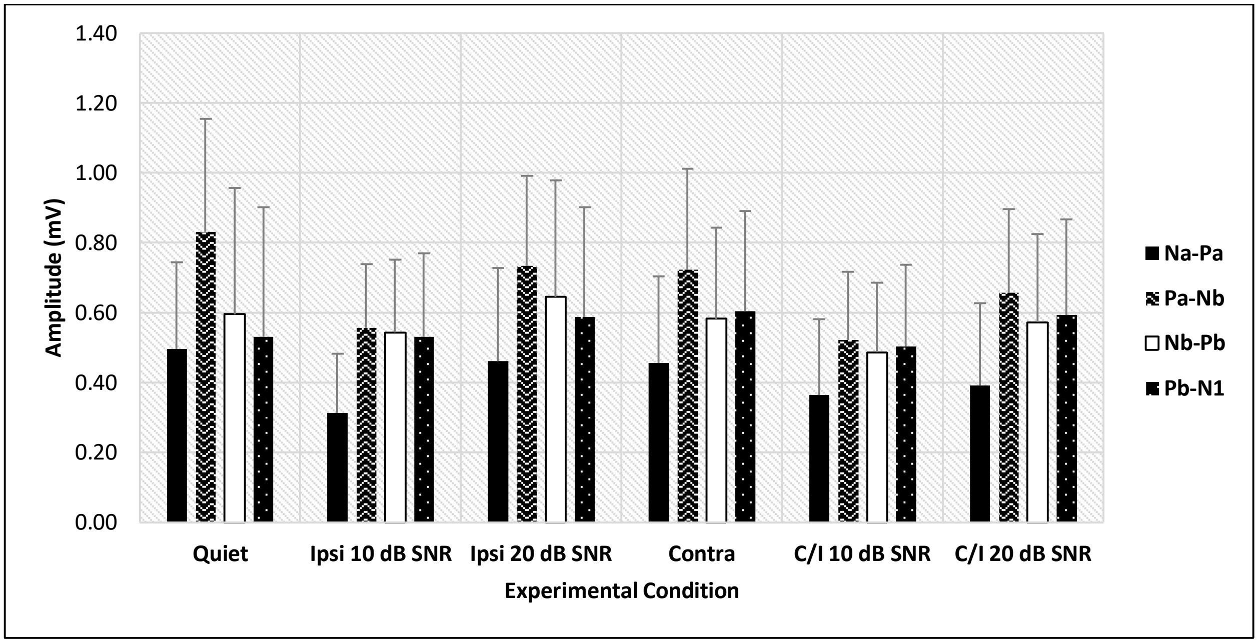


Figure 8. Amplitude changes with condition for each individual MLR component. As is evident by bar graphs, amplitude changes with noise condition also vary by MLR component.

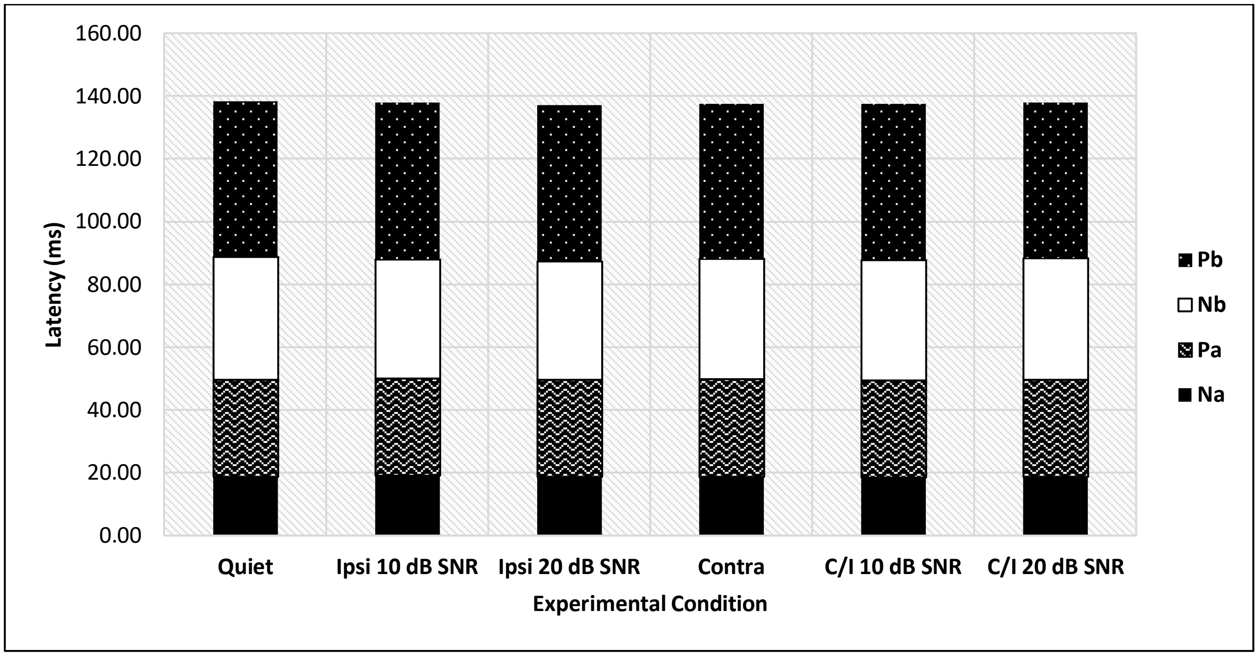


Figure 9. Mean latency for each component are indicated for each noise condition. Component is the parameter.

Ear

There were no ear-related differences in ABR or MLR latencies or amplitudes when measured from the ipsilateral electrode montage (Cz-A1 for the left ear and Cz-A2 for the right ear). There were also no interactions between ear and gender or ear and noise-condition.

Summary of Results

Gender differences in the ABR component wave V and MLR components were found. Females had shorter wave V latencies and larger amplitudes compared to males. Females also had larger MLR amplitudes compared to males, but there were no latency differences. Effects of contralateral noise on amplitudes of the MLR components were found, indicating suppression. Noise condition significantly affected wave V amplitudes and MLR component amplitudes. Latencies also varied with differing noise conditions. Finally, there were no ear differences in either ABR or MLR latencies/amplitudes.

Discussion

In audiology, clinical applications of the MLR include measuring estimations of hearing thresholds (Lenarz, Gülzow, Grözinger, & Hoth, 1986) and evaluating central auditory processing disorders (Kraus & McGee, 1990). Because the MLR is used to evaluate central auditory processing disorders, it is important not only to know how gender might affect the amplitudes and latencies of the MLR, but also how ear and noise conditions possibly affect these component values. Handedness was identified as an important subject characteristic to control for. Mohebbi et al. (2014) found that right-handers had a left hemisphere dominance in Pa amplitude, whereas left-handers did not demonstrate hemisphere dominance. Handedness was not analyzed as a factor due to the low number of left-handers in the study. Only one subject out of 27 had a significant left-hand score according to the Edinburgh Handedness Inventory (Dragovic, 2004). Additionally, it is also important to understand how suppression with low-level noise affects these components compared to a loud noise that might trigger an acoustic reflex, consequently affecting MLR amplitude (Musiek, Charette, Kelly, Lee, & Musiek, 1999), thus altering how any deviations in absolute and inter-peak latencies, and primarily amplitudes are to be interpreted in the diagnosis of CAPD.

Gender Differences in the Auditory System

The results of the current experiment support gender differences in the speech-evoked MLR, that are consistent with previous research using click stimuli for the level of the inner ear (Berninger, 2007; Kei et al., 1997; Keogh, 2001; Liu et al., 2009; Thornton et al., 2003), brainstem (Don et al., 1993; Morlet et al., 1995; Snihur & Hampson, 2011), and auditory thalamus/primary-auditory cortex (Tucker, 2002; Zakaria, Jalaei, & Wahab, 2016). This is in contrast to one other study investigating gender differences in the MLR (Kraus et al., 1985). Unlike other studies, Kraus et al. investigated gender differences in the detection of the MLR between females and male children, while other studies investigated gender differences in the MLR itself.

Gender differences found in other studies, suggest that sex hormones have an influence on the development of the human auditory system (McFadden, 2009). Although there are gender differences in head size and peripheral auditory structures, such as basilar membrane length, these structural differences cannot account for the size of gender differences in auditory evoked potentials. This suggests that underlying auditory neuroanatomy is different for females compared to males and that hormone levels after birth may also play a role.

Previous studies have found differences in cortical white matter between males and females (Kanaan et al., 2012). It is possible that there may be some evolutionary reason as to why the central auditory nervous system differs between genders, resulting in the differences seen in this study and previous studies. These differences are likely triggered by hormone exposure in utero (Swaab, 2007). The extent of functional gender differences in auditory function is debatable (Hyde & Linn, 1988), but research suggests that females may have better hearing sensitivity (Dreisbach, Kramer, Cobos, & Cowart, 2007) and are better at speech reading words when compared to males (Strelnikov et al., 2009), which may be related, at least in part, to the gender differences found in this study to a speech token. Interestingly, despite evidence suggesting that females have a small advantage in speech perception, including speech reading, one study found that females had a higher incidence of disability, related to hearing loss, compared to males (Alexandre et al., 2014).

As seen in animal studies, the hormone of main concern is androgen or estradiol (the converted form of androgen). Since all fetus' begin in a similar state, androgen exposure is what likely determines gender differentiation (Jost, Vigier, Prépin, & Perchellet, 1973). Gender differences are likely not exclusively limited to the categories of male and female, although gender differences outside of these categories might not always be statistically significant. McFadden et al. (1999) found that homosexual females had more masculinized cochlea, which resulted in fewer and weaker spontaneous SOAEs, trending more towards findings for heterosexual males (McFadden & Pasanen, 1999). This is also paralleled in click evoked otoacoustic emissions (CEOAEs) (McFadden, Loehlin, & Pasanen, 1996). There may also be masculinization of the central auditory nervous system for homosexual females. However, the investigators did not find differences between homosexual and heterosexual males. This might be due to the auditory system already being masculinized for homosexual males, reducing significant differences between the two groups.

McFadden (2009) summarized findings regarding gender differences in spotted hyenas, rhesus and marmoset monkeys, and sheep. McFadden found a reduction in the robustness of CEOAEs was associated with high exposure to androgen in utero (McFadden, 2009). Snihur et al. (2012) also showed an effect of testosterone levels on CEOAEs in men and women. ABR latency can change depending on time course of the menstrual cycle in females, also indicating the influence of hormones on auditory nervous system function. Serra et al. (2003) found that absolute and inter-peak latencies were shorter during the periovular stage of the menstrual cycle.

Taking account of fluctuating testosterone levels in men and hormonal changes during the menstrual cycle, it seems that gender differences are not fixed or simple. Gender differences may result from a combination of permanent peripheral and central differences based on gender differences from androgen exposure in utero, and current levels of testosterone in both males and females. This multifaceted gender effect on auditory measures may explain why studies have found gender differences where others have not, especially when not controlling testosterone levels, other hormonal changes, medication, and even gender expression. To date, no study investigating gender difference has considered if these gender differences still exist in transgender individuals and to what extent.

The MLR also changes with increasing hearing loss (Hesse & Gerken, 2002; Van Maanen & Stapells, 2009). Hesse and Gerken (2002) investigated the effect of hearing loss on the amplitude and latency of the MLR and found a significant group difference, resulting in larger Pa-Nb amplitudes and significantly greater Pb-N1 slope, as a function of stimulus level in individuals with hearing loss. In contrast, ABR amplitudes are diminished with increasing hearing loss (Verhulst, Jagadeesh, Mauermann, & Ernst, 2016).

Considering the findings of this study and previous research on MLR with increasing hearing loss, it is possible that gender differences seen in the MLR with normal-hearing subjects may be further exacerbated with various degrees of hearing loss and health conditions, such as chronic smoking, which has been associated with larger Nb-Pb amplitudes and shorter Nb latency (Ramkissoon & Beverly, 2014). Considering that gender differences are greater with older populations and hearing loss greatly affects the amplitude of the MLR, it seems that gender differences found in this paper might be larger amongst older individuals with hearing loss than the general population, thus making it more important to take into account when interpreting audiologic findings. Not considering how individual differences (i.e. gender) affect the latency of the MLR might lead to misdiagnosis in cases where variations in absolute and inter-peak latencies are borderline normal.

Additionally, gender differences in noise exposure from recreation or work may also exacerbate these gender differences (McFadden, 1998), thus it is important to control for noise exposure when investigating gender differences among older individuals and/or individuals with hearing loss. Gender differences in the middle latency response among elderly individuals are unknown, as only two studies, the current study and one other paper, have investigated gender differences in the MLR in adults (Kraus et al., 1985; Tucker, 2002). However, gender differences have been investigated in the MMN, P300, and N400 among elderly participants, revealing that gender differences were maintained in older participants, other than the N400, but were not as robust compared to younger participants (Tsolaki et al., 2015). Tlumak et al. (2015) found that although the long-latency steady-state response remained stable with age, the 40 Hz ASSR, which corresponds to the MLR, was affected after about 40 years of age. It is possible that greater variability of AEPs in general, due to differences in neural integrity (S. Anderson, Parbery-Clark, White-Schwoch, & Kraus, 2012), might reduce overall gender differences in older populations (Tsolaki et al., 2015). In other words, gender differences may exist, but may not be measurable due to high inter-subject variability and difficulty controlling for noise exposure, real-world performance with speech recognition and understanding, and etiology of hearing loss, if any.

The findings of this study impact clinical decision making. Assessments using the MLR should take into consideration gender differences when determining whether deviations from normal peak-to-peak, inter-peak latencies, and amplitudes are significant. Additionally, this study has shown that the MLR can be reliably produced with a speech token for use in objective assessment of hearing at the level of the auditory thalamus and primary auditory cortex.

Suppression and Effects of Noise

Human beings are rarely in quiet situations, so it is important to understand how noise impacts speech understanding. Therefore, this study also investigated contralateral suppression. Additionally, there is rarely a situation when an individual would only have noise in the opposite ear. As a result, the effect of ipsilateral noise alone was also investigated. This was done for two reasons: 1) contralateral/ipsilateral acoustic stimulation is more realistic, and 2) it was also important to investigate whether the addition of ipsilateral noise would improve neural encoding of the speech token. The addition of ipsilateral noise may reduce some of the suppressive effects of the contralateral noise (Chintanpalli, Jennings, Heinz, & Strickland, 2012; Guinan, 2006).

This is sometimes called “release from suppression” or “unmasking”. For this reason, both ipsilateral and contralateral/ipsilateral conditions were included in addition to the contralateral noise condition.

This study showed an effect of contralateral noise, when compared to the quiet condition, for waves V and Pa. However, release from suppression was not evident. Earlier it was mentioned that some studies have found that suppression is beneficial for speech in noise understanding, but that others found that there was no correlation between suppression and the ability to understand speech in noise. The practical implications of release from suppression are also up for debate (Kumar & Vanaja, 2004). Some studies have found no evidence of release from suppression with binaural noise (Berlin et al., 1995). Aside from the practical application of a measure of release from suppression, it is difficult to say why a release from suppression was not evident in the current study, as there are not many studies that investigate using this measure. Suppression effects are very small (although statistically significant) and a “release from suppression”, unless it brought the response back to the unsuppressed condition, would be very difficult to measure using the methods used in this study.

Ear/Laterality

In contrast to previous research on click-evoked OAEs and ABRs, no significant ear differences in MLR latency or amplitude were found. Although, previous studies have demonstrated ear differences for MLR or 40 Hz ASSR. A trend of right hemisphere dominance was found for the 40 Hz ASSR as measured by magnetoencephalography (MEG) using a sinusoidal tone as the carrier frequency (Ross et al., 2005). Weihing and Musiek (2014) found ear-test order more greatly impacted subject variability in older adults. The ear-effect was calculated by categorizing waves as either lower-amplitude or higher-amplitude, rather than focusing on left versus right, as this might vary between individuals. For the MLR evoked by a 1000 Hz tone-pip, differences were significantly larger in older adults compared to young adults. In both studies, tones, rather than a complex speech-token were used. Anderson (2011) investigated lateralization of the MLR to the speech token /da/ finding no differences between left and right sides for the whole token. The paper went on to discuss the possibility that at the level of the MLR (i.e. auditory thalamus and primary auditory cortex) auditory information is coded spatially rather than comparing right and left ears. It may be that ear differences were eliminated by eliciting the MLR with a speech token, either due to its complexity or its resemblance of speech, as both the present study and one other study (J. M. Anderson, 2011) did not find differences between ears in the speech-evoked MLR.

Conclusion

Investigating gender differences are important to understanding the central auditory system and what patient characteristics impact differences in hearing in quiet and in noise. The current study has found gender differences in the speech-evoked MLR, evidence of contralateral suppression, and an effect of noise condition on ABR/MLR component amplitudes. The gender differences found in this study agree with previous studies that have found gender differences at the level of the inner ear, brainstem, and auditory thalamus in the click-evoked MLR. However, ear differences and release from suppression were not evident, which may reflect a difference between the MLR evoked by a speech-token and a simple stimulus, such as a click. Further research is needed to confirm gender differences found in the click-evoked and speech-evoked MLR and investigate how more complex manifestations of gender, such as transgender identities, influence these differences.

Appendices

Appendix A: Descriptive statistics of group average for wave V latency by condition

Gender	Condition	Mean	Std. Dev.	Std. Error	Minimum	Maximum
Left						
TOTAL		**8.479**	**0.868**	**0.034**	**4.8**	**11.7**
F	Contra	8.084	0.515	0.097	7.2	9.6
F	Contra/Ipsi 10 dB SNR	8.791	1.069	0.202	6	11.25
F	Contra/Ipsi 20 dB SNR	8.62	0.858	0.162	6.75	10.8
F	Ipsi 10 dB SNR	8.341	1.265	0.239	5.4	10.65
F	Ipsi 20 dB SNR	8.266	0.817	0.154	5.55	9.45
F	Quiet	8.014	0.317	0.06	7.5	8.85
M	Contra	8.308	0.457	0.09	7.5	9.15
M	Contra/Ipsi 10 dB SNR	8.625	1.108	0.217	5.55	10.95
M	Contra/Ipsi 20 dB SNR	8.325	1.119	0.22	4.8	9.45
M	Ipsi 10 dB SNR	9.185	0.801	0.157	7.05	10.8
M	Ipsi 20 dB SNR	8.55	0.5	0.098	7.65	9.75
M	Quiet	8.244	0.468	0.092	7.2	9
Right						
F	Contra	7.977	0.462	0.087	6.9	9.15
F	Contra/Ipsi 10 dB SNR	8.7	1.164	0.22	5.85	11.25
F	Contra/Ipsi 20 dB SNR	8.679	1.02	0.193	6.9	11.4
F	Ipsi 10 dB SNR	8.502	0.799	0.151	7.05	9.9
F	Ipsi 20 dB SNR	8.416	0.669	0.126	7.5	11.25
F	Quiet	7.875	0.687	0.13	6	9.45
M	Contra	8.44	0.436	0.085	7.5	9.15
M	Contra/Ipsi 10 dB SNR	8.908	1.095	0.215	6.75	11.7
M	Contra/Ipsi 20 dB SNR	8.74	0.519	0.102	7.65	9.75
M	Ipsi 10 dB SNR	8.833	1.087	0.213	6.45	10.95
M	Ipsi 20 dB SNR	8.787	0.769	0.151	7.65	11.7
M	Quiet	8.394	0.578	0.113	7.35	9.75

Appendix B: Descriptive statistics of group average for wave V amplitude by condition

Gender	Condition	Mean	Std. Dev.	Std. Error	Minimum	Maximum
Left						
TOTAL		**0.22**	**0.152**	**0.006**	**0**	**1.05**
F	**Contra**	0.246	0.155	0.029	0.06	0.61
F	**Contra/Ipsi 10 dB SNR**	0.168	0.196	0.037	0	0.92
F	**Contra/Ipsi 20 dB SNR**	0.159	0.165	0.031	0	0.84
F	**Ipsi 10 dB SNR**	0.191	0.127	0.024	0.03	0.58
F	**Ipsi 20 dB SNR**	0.29	0.221	0.042	0	1.05
F	**Quiet**	0.353	0.155	0.029	0.12	0.77
M	**Contra**	0.253	0.117	0.023	0.05	0.48
M	**Contra/Ipsi 10 dB SNR**	0.143	0.089	0.017	0.01	0.33
M	**Contra/Ipsi 20 dB SNR**	0.163	0.114	0.022	0.02	0.44
M	**Ipsi 10 dB SNR**	0.162	0.079	0.015	0.01	0.3
M	**Ipsi 20 dB SNR**	0.224	0.103	0.02	0.07	0.41
M	**Quiet**	0.32	0.152	0.03	0.06	0.7
Right						
F	**Contra**	0.29	0.136	0.026	0.08	0.59
F	**Contra/Ipsi 10 dB SNR**	0.17	0.109	0.021	0.02	0.45
F	**Contra/Ipsi 20 dB SNR**	0.228	0.139	0.026	0	0.59
F	**Ipsi 10 dB SNR**	0.169	0.133	0.025	0	0.58
F	**Ipsi 20 dB SNR**	0.205	0.12	0.023	0	0.56
F	**Quiet**	0.302	0.163	0.031	0.04	0.71
M	**Contra**	0.262	0.121	0.024	0.05	0.56
M	**Contra/Ipsi 10 dB SNR**	0.172	0.164	0.032	0.01	0.88
M	**Contra/Ipsi 20 dB SNR**	0.177	0.169	0.033	0.02	0.88
M	**Ipsi 10 dB SNR**	0.132	0.067	0.013	0	0.27
M	**Ipsi 20 dB SNR**	0.195	0.098	0.019	0.01	0.44
M	**Quiet**	0.309	0.16	0.031	0.08	0.66

Appendix C: Descriptive statistics of group average for wave Na latency by condition

Gender	Condition	Mean	Std. Dev.	Std. Error	Minimum	Maximum
Left						
TOTAL		**18.955**	**2.074**	**0.081**	**12.75**	**25.2**
F	**Contra**	18.793	2.227	0.421	12.75	21.15
F	**Contra/Ipsi 10 dB SNR**	18.198	2.38	0.45	13.5	22.2
F	**Contra/Ipsi 20 dB SNR**	18.332	2.408	0.455	12.9	22.05
F	**Ipsi 10 dB SNR**	18.745	1.882	0.356	14.85	21.6
F	**Ipsi 20 dB SNR**	18.295	1.884	0.356	12.75	21.45
F	**Quiet**	18.177	1.966	0.372	12.9	21
M	**Contra**	19.615	1.945	0.381	15.6	22.5
M	**Contra/Ipsi 10 dB SNR**	19.765	1.985	0.389	15.6	25.2
M	**Contra/Ipsi 20 dB SNR**	19.385	1.642	0.322	16.35	21.6
M	**Ipsi 10 dB SNR**	19.863	1.582	0.31	16.5	22.5
M	**Ipsi 20 dB SNR**	19.8	1.652	0.324	16.05	22.05
M	**Quiet**	19.644	1.771	0.347	14.85	22.05
Right						
F	**Contra**	18.027	2.531	0.478	13.5	24.15
F	**Contra/Ipsi 10 dB SNR**	18.332	2.232	0.422	14.25	22.2
F	**Contra/Ipsi 20 dB SNR**	18.22	1.695	0.32	14.7	21
F	**Ipsi 10 dB SNR**	18.67	2.271	0.429	13.65	21.45
F	**Ipsi 20 dB SNR**	18.605	1.701	0.321	13.5	21.6
F	**Quiet**	18.643	1.669	0.315	5	21.6
M	**Contra**	19.477	2.173	0.426	14.4	22.05
M	**Contra/Ipsi 10 dB SNR**	18.773	2.287	0.449	13.95	22.35
M	**Contra/Ipsi 20 dB SNR**	19.327	2.009	0.394	14.4	22.05
M	**Ipsi 10 dB SNR**	20.071	1.785	0.35	16.05	22.5
M	**Ipsi 20 dB SNR**	19.229	2.231	0.437	15.45	22.5
M	**Quiet**	19.425	1.889	0.37	15.9	22.65

Appendix D: Descriptive statistics of group average for wave Na amplitude by condition

Gender	Condition	Mean	Std. Dev.	Std. Error	Minimum	Maximum
Left						
TOTAL		**0.414**	**0.24**	**0.009**	**0**	**1.83**
F	**Contra**	0.478	0.292	0.055	0.08	1.27
F	**Contra/Ipsi 10 dB SNR**	0.449	0.331	0.063	0.06	1.44
F	**Contra/Ipsi 20 dB SNR**	0.446	0.34	0.064	0.08	1.77
F	**Ipsi 10 dB SNR**	0.365	0.233	0.044	0.01	0.87
F	**Ipsi 20 dB SNR**	0.564	0.309	0.058	0.18	1.47
F	**Quiet**	0.554	0.276	0.052	0.12	1.36
M	**Contra**	0.426	0.183	0.036	0.09	0.9
M	**Contra/Ipsi 10 dB SNR**	0.322	0.123	0.024	0.01	0.64
M	**Contra/Ipsi 20 dB SNR**	0.374	0.127	0.025	0.15	0.63
M	**Ipsi 10 dB SNR**	0.306	0.122	0.024	0.05	0.49
M	**Ipsi 20 dB SNR**	0.402	0.152	0.03	0.08	0.72
M	**Quiet**	0.432	0.126	0.025	0.24	0.63
Right						
F	**Contra**	0.53	0.307	0.058	0.16	1.7
F	**Contra/Ipsi 10 dB SNR**	0.367	0.202	0.038	0.1	0.97
F	**Contra/Ipsi 20 dB SNR**	0.405	0.236	0.045	0.12	1.46
F	**Ipsi 10 dB SNR**	0.297	0.169	0.032	0.02	0.67
F	**Ipsi 20 dB SNR**	0.51	0.346	0.065	0.14	1.83
F	**Quiet**	0.532	0.338	0.064	0	1.61
M	**Contra**	0.382	0.146	0.029	0.2	0.68
M	**Contra/Ipsi 10 dB SNR**	0.309	0.105	0.021	0.09	0.56
M	**Contra/Ipsi 20 dB SNR**	0.34	0.154	0.03	0.09	0.55
M	**Ipsi 10 dB SNR**	0.282	0.117	0.023	0.04	0.64
M	**Ipsi 20 dB SNR**	0.355	0.139	0.027	0.13	0.63
M	**Quiet**	0.463	0.166	0.033	0.19	1.04

Appendix E: Descriptive statistics of group average for wave Pa latency by condition

Gender	Condition	Mean	Std. Dev.	Std. Error	Minimum	Maximum
Left						
TOTAL		**30.924**	**1.709**	**0.067**	**25.65**	**39.75**
F	**Contra**	30.664	1.556	0.294	26.85	34.2
F	**Contra/Ipsi 10 dB SNR**	30.337	2.01	0.38	26.25	34.35
F	**Contra/Ipsi 20 dB SNR**	30.787	1.645	0.311	25.95	32.25
F	**Ipsi 10 dB SNR**	31.029	1.861	0.352	27.15	33.75
F	**Ipsi 20 dB SNR**	30.37	1.426	0.269	27.6	32.25
F	**Quiet**	30.632	1.427	0.27	27.15	33.15
M	**Contra**	31.327	1.031	0.202	27.3	32.55
M	**Contra/Ipsi 10 dB SNR**	31.108	1.905	0.374	27.9	33.3
M	**Contra/Ipsi 20 dB SNR**	31.517	1.33	0.261	26.25	33.45
M	**Ipsi 10 dB SNR**	30.837	2.102	0.412	26.85	34.05
M	**Ipsi 20 dB SNR**	31.575	0.905	0.178	28.35	33
M	**Quiet**	31.194	1.296	0.254	27.15	32.7
Right						
F	**Contra**	30.541	1.271	0.24	26.7	31.65
F	**Contra/Ipsi 10 dB SNR**	30.702	1.807	0.341	27.3	33.45
F	**Contra/Ipsi 20 dB SNR**	30.455	1.5	0.284	27.15	32.7
F	**Ipsi 10 dB SNR**	29.871	1.974	0.373	27	32.7
F	**Ipsi 20 dB SNR**	30.648	1.44	0.272	27.45	32.2
F	**Quiet**	29.829	1.898	0.359	26.1	33.75
M	**Contra**	31.91	2.054	0.403	26.55	39.75
M	**Contra/Ipsi 10 dB SNR**	31.338	1.827	0.358	27.3	33.45
M	**Contra/Ipsi 20 dB SNR**	31.16	1.963	0.385	26.1	33.45
M	**Ipsi 10 dB SNR**	31.892	1.742	0.342	27.3	34.65
M	**Ipsi 20 dB SNR**	31.287	1.748	0.343	25.65	34.5
M	**Quiet**	31.558	0.846	0.166	28.35	32.7

Appendix F: Descriptive statistics of group average for wave Pa amplitude by condition

Gender	Condition	Mean	Std. Dev.	Std. Error	Minimum	Maximum
Left						
TOTAL		**0.671**	**0.273**	**0.011**	**0.1**	**2.84**
F	Contra	0.704	0.395	0.075	0.22	1.65
F	Contra/Ipsi 10 dB SNR	0.554	0.253	0.048	0.24	1.35
F	Contra/Ipsi 20 dB SNR	0.646	0.292	0.055	0.25	1.32
F	Ipsi 10 dB SNR	0.526	0.182	0.034	0.01	0.83
F	Ipsi 20 dB SNR	0.776	0.303	0.057	0.39	1.61
F	Quiet	0.832	0.318	0.06	0.22	1.44
M	Contra	0.723	0.202	0.04	0.24	1.16
M	Contra/Ipsi 10 dB SNR	0.514	0.179	0.035	0.13	1.08
M	Contra/Ipsi 20 dB SNR	0.657	0.18	0.035	0.33	1.02
M	Ipsi 10 dB SNR	0.586	0.134	0.026	0.35	0.81
M	Ipsi 20 dB SNR	0.726	0.189	0.037	0.42	1.27
M	Quiet	0.846	0.227	0.044	0.5	1.33
Right						
F	Contra	0.773	0.301	0.057	0.24	1.6
F	Contra/Ipsi 10 dB SNR	0.513	0.21	0.04	0.17	1.07
F	Contra/Ipsi 20 dB SNR	0.709	0.266	0.05	0.37	1.45
F	Ipsi 10 dB SNR	0.541	0.232	0.044	0.13	1.23
F	Ipsi 20 dB SNR	0.71	0.311	0.059	0.01	1.63
F	Quiet	0.83	0.474	0.09	0.39	2.84
M	Contra	0.688	0.212	0.042	0.29	1.15
M	Contra/Ipsi 10 dB SNR	0.505	0.101	0.02	0.33	0.71
M	Contra/Ipsi 20 dB SNR	0.612	0.195	0.038	0.32	1.15
M	Ipsi 10 dB SNR	0.578	0.163	0.032	0.35	0.97
M	Ipsi 20 dB SNR	0.723	0.203	0.04	0.4	1.11
M	Quiet	0.82	0.206	0.04	0.47	1.27

Appendix G: Descriptive statistics of group average for wave Nb latency by condition

Gender	Condition	Mean	Std. Dev.	Std. Error	Minimum	Maximum
Left						
TOTAL		**38.312**	**3.3**	**0.13**	**31.05**	**48**
F	**Contra**	37.939	3.856	0.729	33.3	45
F	**Contra/Ipsi 10 dB SNR**	39.225	3.882	0.734	32.85	46.8
F	**Contra/Ipsi 20 dB SNR**	39.032	3.957	0.748	34.2	45.3
F	**Ipsi 10 dB SNR**	38.936	3.07	0.58	35.1	45.45
F	**Ipsi 20 dB SNR**	38.861	3.362	0.635	34.8	45.75
F	**Quiet**	39.98	3.887	0.735	32.85	46.5
M	**Contra**	39.26	4.063	0.797	33.75	46.8
M	**Contra/Ipsi 10 dB SNR**	37.587	1.935	0.379	34.65	43.35
M	**Contra/Ipsi 20 dB SNR**	38.36	3.553	0.697	33.6	45.9
M	**Ipsi 10 dB SNR**	37.437	0.709	0.139	36.3	38.85
M	**Ipsi 20 dB SNR**	37.373	1.791	0.351	33.75	42.9
M	**Quiet**	38.746	3.232	0.634	35.4	45
Right						
F	**Contra**	37.323	3.442	0.651	31.05	43.05
F	**Contra/Ipsi 10 dB SNR**	37.623	2.407	0.455	34.65	45.6
F	**Contra/Ipsi 20 dB SNR**	37.859	3.263	0.617	34.05	45.6
F	**Ipsi 10 dB SNR**	37.436	2.034	0.384	34.35	44.55
F	**Ipsi 20 dB SNR**	37.189	2.894	0.547	31.2	45.9
F	**Quiet**	38.202	3.603	0.681	32.55	43.8
M	**Contra**	38.602	4.179	0.82	33.45	46.95
M	**Contra/Ipsi 10 dB SNR**	38.833	3.737	0.733	34.2	46.8
M	**Contra/Ipsi 20 dB SNR**	39.363	4.728	0.927	33.15	48
M	**Ipsi 10 dB SNR**	37.408	1.57	0.308	34.05	39.75
M	**Ipsi 20 dB SNR**	37.102	1.384	0.271	33.9	39.15
M	**Quiet**	39.819	3.349	0.657	35.85	46.8

Appendix H: Descriptive statistics of group average for wave Nb amplitude by condition

Gender	Condition	Mean	Std. Dev.	Std. Error	Minimum	Maximum
Left						
TOTAL		**0.571**	**0.278**	**0.011**	**0.12**	**2.92**
F	**Contra**	0.636	0.236	0.045	0.28	1.25
F	**Contra/Ipsi 10 dB SNR**	0.518	0.186	0.035	0.24	1.03
F	**Contra/Ipsi 20 dB SNR**	0.648	0.244	0.046	0.32	1.26
F	**Ipsi 10 dB SNR**	0.534	0.19	0.036	0.26	0.98
F	**Ipsi 20 dB SNR**	0.646	0.307	0.058	0.16	1.38
F	**Quiet**	0.605	0.251	0.047	0.2	1.05
M	**Contra**	0.521	0.204	0.04	0.16	1.03
M	**Contra/Ipsi 10 dB SNR**	0.475	0.179	0.035	0.21	1
M	**Contra/Ipsi 20 dB SNR**	0.537	0.256	0.05	0.25	1.18
M	**Ipsi 10 dB SNR**	0.539	0.191	0.037	0.3	1.04
M	**Ipsi 20 dB SNR**	0.622	0.277	0.054	0.22	1.42
M	**Quiet**	0.577	0.332	0.065	0.16	1.64
Right						
F	**Contra**	0.66	0.275	0.052	0.29	1.52
F	**Contra/Ipsi 10 dB SNR**	0.544	0.236	0.045	0.27	1.45
F	**Contra/Ipsi 20 dB SNR**	0.608	0.222	0.042	0.34	1.27
F	**Ipsi 10 dB SNR**	0.574	0.17	0.032	0.31	0.84
F	**Ipsi 20 dB SNR**	0.712	0.413	0.078	0.3	2.4
F	**Quiet**	0.67	0.505	0.095	0.26	2.92
M	**Contra**	0.506	0.291	0.057	0.22	1.39
M	**Contra/Ipsi 10 dB SNR**	0.404	0.169	0.033	0.14	0.75
M	**Contra/Ipsi 20 dB SNR**	0.492	0.268	0.053	0.23	1.12
M	**Ipsi 10 dB SNR**	0.53	0.273	0.054	0.19	1.15
M	**Ipsi 20 dB SNR**	0.597	0.32	0.063	0.12	1.39
M	**Quiet**	0.525	0.303	0.059	0.18	1.33

Appendix I: Descriptive statistics of group average for wave Pb latency by condition

Gender	Condition	Mean	Std. Dev.	Std. Error	Minimum	Maximum
Left						
TOTAL		49.552	2.08	0.082	42.75	59.1
F	Contra	48.761	1.755	0.332	45.3	53.85
F	Contra/Ipsi 10 dB SNR	49.618	1.705	0.322	46.65	53.85
F	Contra/Ipsi 20 dB SNR	49.371	1.329	0.251	47.4	52.35
F	Ipsi 10 dB SNR	49.591	1.922	0.363	45.15	53.1
F	Ipsi 20 dB SNR	49.13	1.447	0.273	46.05	52.05
F	Quiet	49.227	2.866	0.542	42.75	55.05
M	Contra	49.465	1.34	0.263	47.85	52.5
M	Contra/Ipsi 10 dB SNR	50.065	1.76	0.345	46.2	54.3
M	Contra/Ipsi 20 dB SNR	49.748	1.67	0.327	46.8	54.6
M	Ipsi 10 dB SNR	50.579	1.838	0.36	46.95	54.15
M	Ipsi 20 dB SNR	49.904	1.453	0.285	47.1	52.8
M	Quiet	49.852	2.544	0.499	47.1	56.1
Right						
F	Contra	48.487	1.957	0.37	45.3	54.3
F	Contra/Ipsi 10 dB SNR	49.066	1.507	0.285	45.6	51.9
F	Contra/Ipsi 20 dB SNR	48.729	1.382	0.261	45	52.2
F	Ipsi 10 dB SNR	49.023	2.273	0.43	45	53.1
F	Ipsi 20 dB SNR	48.739	2.143	0.405	44.7	52.95
F	Quiet	49.109	3.081	0.582	42.75	53.85
M	Contra	50.048	2.269	0.445	47.4	57.3
M	Contra/Ipsi 10 dB SNR	49.967	1.778	0.349	45.9	53.7
M	Contra/Ipsi 20 dB SNR	50.256	2.403	0.471	47.25	59.1
M	Ipsi 10 dB SNR	50.515	1.899	0.372	46.5	52.95
M	Ipsi 20 dB SNR	50.365	2.452	0.481	45	57.15
M	Quiet	50.071	2.549	0.5	46.35	55.65

Appendix J: Descriptive Statistics- Group average for wave Pb amplitude by condition

Gender	Condition	Mean	Std. Dev.	Std. Error	Minimum	Maximum
Left						
TOTAL		**0.559**	**0.291**	**0.011**	**0.1**	**2.98**
F	Contra	0.648	0.263	0.05	0.24	1.32
F	Contra/Ipsi 10 dB SNR	0.548	0.218	0.041	0.21	1.21
F	Contra/Ipsi 20 dB SNR	0.672	0.28	0.053	0.3	1.31
F	Ipsi 10 dB SNR	0.616	0.243	0.046	0.31	1.1
F	Ipsi 20 dB SNR	0.638	0.236	0.045	0.32	1.22
F	Quiet	0.545	0.18	0.034	0.19	0.92
M	Contra	0.543	0.271	0.053	0.18	1.25
M	Contra/Ipsi 10 dB SNR	0.45	0.15	0.029	0.12	0.79
M	Contra/Ipsi 20 dB SNR	0.519	0.226	0.044	0.1	1.07
M	Ipsi 10 dB SNR	0.487	0.158	0.031	0.28	0.94
M	Ipsi 20 dB SNR	0.564	0.281	0.055	0.12	1.33
M	Quiet	0.477	0.344	0.068	0.11	1.49
Right						
F	Contra	0.691	0.283	0.053	0.35	1.48
F	Contra/Ipsi 10 dB SNR	0.627	0.294	0.056	0.36	1.78
F	Contra/Ipsi 20 dB SNR	0.698	0.243	0.046	0.24	1.22
F	Ipsi 10 dB SNR	0.575	0.263	0.05	0.24	1.23
F	Ipsi 20 dB SNR	0.63	0.387	0.073	0.22	2.29
F	Quiet	0.614	0.551	0.104	0.15	2.98
M	Contra	0.53	0.304	0.06	0.14	1.23
M	Contra/Ipsi 10 dB SNR	0.374	0.166	0.033	0.19	0.82
M	Contra/Ipsi 20 dB SNR	0.475	0.284	0.056	0.11	1.17
M	Ipsi 10 dB SNR	0.435	0.245	0.048	0.19	1.16
M	Ipsi 20 dB SNR	0.518	0.325	0.064	0.22	1.46
M	Quiet	0.483	0.3	0.059	0.15	1.29

References

Agung, K., Purdy, S. C., McMahon, C. M., & Newall, P. (2006). The Use of Cortical Auditory Evoked Potentials to Evaluate Neural Encoding of Speech Sounds in Adults. *Journal of the American Academy of Audiology, 17*, 559-572.

Alexandre, T. d. S., Corona, L. P., Nunes, D. P., Santos, J. L. F., Duarte, Y. A. d. O., & Lebrão, M. L. (2014). Disability in instrumental activities of daily living among older adults: gender differences. *Revista de Saúde Pública, 48*(3), 379-389. doi:10.1590/s0034-8910.2014048004754

Anderson, J. M. (2011). *Lateralization Effects of Brainstem Responses and Middle Latency Responses to a Complex Tone and Speech Syllable.* (Doctor of Philosophy), University of Cincinnati, Cincinnati, OH. (201)

Anderson, S., Parbery-Clark, A., White-Schwoch, T., & Kraus, N. (2012). Aging affects neural precision of speech encoding. *JOURNAL OF NEUROSCIENCE, 32*(41), 14156-14164.

Berlin, C. I., Hood, L. J., Hurley, A. E., Wen, H., & Kemp, D. T. (1995). Binaural noise suppresses linear click-evoked otoacoustic emissions more than ipsilateral or contralateral noise. *Hearing Research, 87*, 96-103.

Berninger, E. (2007). Characteristics of normal newborn transient-evoked otoacoustic emissions: ear asymmetries and sex effects. *International Journal of Audiology, 46*(11), 661-669.

Chintanpalli, A., Jennings, S. G., Heinz, M. G., & Strickland, E. A. (2012). Modeling the anti-masking effects of the olivocochlear reflex in auditory nerve responses to tones in sustained noise. *Journal of the Association for Research Otolaryngology, 13*(2), 219-235.

Clark, J. H. (1981). Uses and abuses of hearing loss classification. *Asha, 23*(7), 493-500.

de Boer, J., Thornton, A. R. D., & Krumbholz, K. (2012). What is the role of the medial olivocochlear system in speech-in-noise processing? *Journal of Neurophysiology, 107*, 1301-1312.

Don, M., Ponton, C. W., Eggermont, J. J., & Masuda, A. (1993). Gender differences in cochlear response time: An explanation for gender amplitude differences in the unmasked auditory brain-stem response. *The Journal of the Acoustical Society of America, 94*(4), 2135-2148.

Dragovic, M. (2004). Towards an improved measure of the Edinburgh Handedness Inventory: a one-factor congeneric measurement model using confirmatory factor analysis. *Laterality, 9*(4), 411-419.

Dreisbach, L. E., Kramer, S. J., Cobos, S., & Cowart, K. (2007). Racial and gender effects on pure-tone thresholds and distortion-product otoacoustic emissions (DPOAEs) in normal-hearing young adults. *International Journal of Audiology, 46*, 419-426. doi:0.1080/14992020701355074

Durante, A. S., & Carvallo, R. M. M. (2002). Contralateral suppression of otoacoustic emissions in neonates. *International Journal of Audiology, 41*, 211-215.

Elkind-Hirsch, K. E., Wallace, E., Malinak, L. R., & Jerger, J. J. (1994). Sex hormones regulate ABR latency. *Otolaryngology - Head and Neck Surgery, 110*(1), 46-52.

Garinis, A. C., Glattke, T., & Cone, B. K. (2011). The MOC Reflex During Active Listening to Speech. *Jounral of Speech, Language, and Hearing Research, 54*, 1464-1476.

Garinis, A. C., Werner, L., & Abdala, C. (2011). The relationship between MOC reflex and masked threshold. *Hearing Research, 282*(1-2), 128-137.

Giraud, A. L., Garnier, S., Micheyl, C., Lina, G., Chays, A., & Chéry-Croze, S. (1997). Auditory efferents involved in speech-in-noise intelligibility. *NeuroReport, 8*, 1779-1783.

Guinan, J. J. (2006). Olivocochlear Efferents: Anatomy, Physiology, Function, and the Measurement of Efferent Effects in Humans. *Ear and Hearing, 27*(6), 589-607.

Haggard, M. P., & Parkinson, A. M. (1971). Stimulus and task factors as determinants of ear advantages. *The Quarterly Journal of Experimental Psychology, 23*(2), 168-177.

Harkrider, A. W., & Smith, S. B. (2005). Acceptable noise level, phoneme recognition in noise, and measures of auditory efferent activity. *Journal of the American Academy of Audiology, 16*, 530-545.

Hesse, P. A. S., & Gerken, G. M. (2002). Amplitude-intensity functions for audiotry middle latency responses in hearing-impaired subjects. *Hearing Research, 166*, 143-149.

Hyde, J. S., & Linn, M. C. (1988). Gender differences in verbal ability: A meta-analysis.

Jerger, J., Oliver, T., & Chmiel, R. (1988). Auditory middle latency response: A perspective. *Seminars in Hearing, 9*(1), 75-85.

Jost, A., Vigier, B., Prépin, J., & Perchellet, J. P. (1973). *Studies on Sex Differentiation in Mammals*. Retrieved from New York, NY:

Kanaan, R. A., Allin, M., Picchioni, M., Barker, G. J., Daly, E., Shergill, S. S., . . . McGuire, P. K. (2012). Gender differences in white matter microstructure: e38272. *PLoS One U6, 7*(6). doi:10.1371/journal.pone.0038272

Kankkunen, A., & Rosenhall, U. (1985). Comparison between thresholds obtained with pure-tone audiometry and the 40-Hz middle latency response. *Scandinavian Audiology, 14*, 99-104.

Keefe, D. H., Gorga, M. P., Jesteadt, W., & Smith, L. M. (2008). Ear asymmetries in middle-ear, cochlear, and brainstem responses in human infants. *The Journal of the Acoustical Society of America, 123*(3), 1504-1512.

Kei, J., McPherson, B., Smyth, V., Latham, S., & Loscher, J. (1997). Transient evoked otoacoustic emissions in infants: Effects of gender, ear asymmetry and activity status. *International Journal of Audiology, 36*(2), 61-71.

Keogh, T. K., J.; Driscoll, C.; Smyth, V. (2001). Distortion-product otoacoustic emissions in schoolchildren: effects of ear asymmetry, handedness, and gender. *Journal of the American Academy of Audiology, 12*, 506-513.

Kraus, N., & McGee, T. (1990). Clinical applications of the middle latency response. *Journal of the American Academy of Audiology, 1*(3), 130-133.

Kraus, N., Smith, D. I., Reed, N. L., Stein, L. K., & Cartee, C. (1985). Auditory middle latency responses in children: effects of age and diagnostic category. *Electroencephalography and Clinical Neurophysiology, 62*, 343-351.

Kreutzer, J. S., DeLuca, J., & Caplan, B. (2011). *Edinburgh Handedness Inventory*. New York London: Springer.

Krizman, J., Skoe, E., & Kraus, N. (2010). Stimulus rate and subcortical auditory processing of speech. *Audiology & Neurotology, 15*, 332-342.

Krizman, J., Skoe, E., & Kraus, N. (2012). Sex differences in auditory subcortical function. *Clinical Neurophysiology, 123*(3), 590-597.

Kumar Neupane, A., Gururaj, K., Mehta, G., & Sinha, S. K. (2014). Effect of repetition rate on speech evoked auditory brainstem response in younger and middle aged individuals. *Audiology Research, 4*(1), 106.

Kumar, U. A., & Vanaja, C. S. (2004). Functioning of olivocochlear bundle and speech perception in noise. *EAR AND HEARING, 25*(2), 142-146.

Lavoie, B. A., Mehta, R., & Thornton, A. R. D. (2008). Linear and nonlinear changes in the auditory brainstem response of aging humans. *Clinical Neurophysiology, 119*(4), 772-785.

Lehmann, A., & Schönwiesner, M. (2014). Selective attention modulates human auditory brainstem responses: relative contributions of frequency and spatial cues. *PLoS One, 9*(1), e85442.

Lenarz, T., Gülzow, J., Grözinger, M., & Hoth, S. (1986). Clinical evaluation of 40-Hz middle-latency responses in adults: Frequency specific threshold estimation and suprathreshold amplitude characteristics. *Journal for Oto-Rhino-Laryngology and its Related Specialties, 48*(1), 24-32.

Liu, J., Wang, N., Li, J., Shi, B., & Wang, H. (2009). Frequency distribution of synchronized spontaneous otoacoustic emissions showing sex-dependent differences and asymmetry between ears in 2- to 4-day-old neonates. *International Journal of Pediatric Otorhinolaryngology, 73*(5), 731-736.

Matas, C. G., Silva, F. N. O., Leite, R. A., & Samelli, A. G. (2010). Study of suppression effect in the brainstem auditory evoked potential. *Pró-Fono Revista de Atualizaçâo Cientifica, 22*(3), 281-286.

McFadden, D. (1993). A masculinizing effect on the auditory systems of human females having male co-twins. *Proceedings of the National Academy of Sciences, 90*, 11900-11904.

McFadden, D. (1998). Sex differences in the auditory system. *Developmental Neuropsychology, 14*(2-3), 261-298.

McFadden, D. (2002). Masculinization effects in the auditory system. *Archives of Sexual Behavior, 31*(1), 99-111.

McFadden, D. (2009). Masculinization of the mammalian cochlea. *Hearing Research, 252*(1-2), 37-48.

McFadden, D., Hsieh, M. D., Garcia-Sierra, A., & Champlin, C. A. (2010). Differences by sex, ear, and sexual orientation in the time intervals between successive peaks in auditory evoked potentials. *Hear Res, 270*(1-2), 56-64.

McFadden, D., Loehlin, J. C., & Pasanen, E. G. (1996). Additional findings on heritability and prenatal masculinization of cochlear mechanisms: Click-evoked otoacoustic emissions. *Hearing Research, 97*, 102-119.

McFadden, D., & Pasanen, E. G. (1999). Spontaneous otoacoustic emissions in heterosexuals, homosexuals, and bisexuals. *The Journal of the Acoustical Society of America, 105*(4), 2403-2413.

Milenkovic, S., & Dragovic, M. (2013). Modification of the Edinburgh Handedness Inventory: a replication study. *Laterality, 18*(3), 340-348.

Mohebbi, M., Mahmoudian, S., Alborzi, M. S., Najafi-Koopaie, M., Farahani, E. D., & Farhadi, M. (2014). Auditory middle latency responses differ in right- and left-handed subjects: An evaluation through topographic brain mapping. *AMERICAN JOURNAL OF AUDIOLOGY, 23*(3), 273-281.

Morlet, T., Lapillonne, A., Ferber, C., Duclaux, R., Sann, L., Putet, G., . . . Collet, L. (1995). Spontaneous otoacoustic emissions in preterm neonates: prevalence and gender effects. *Hearing Research, 90*, 44-54.

Musiek, F. E., Baran, J., & Pinheiro, M. (1992). P300 results in patients with lesions of the auditory areas of the cerebrum. *Journal of the American Academy of Audiology, 3*(1), 5-15.

Musiek, F. E., Charette, L., Kelly, T., Lee, W. W., & Musiek, E. (1999). Hit and false-positive rates for the middle latency response in patients with central nervous system involvement. *Journal of the American Academy of Audiology, 10*, 124-132.

Müller, M. M., Keil, A., Kissler, J., & Gruber, T. (2001). Suppression of the auditory middle-latency response and evoked gamma-band response in a paired-click paradigm. *Experimental Brain Research, 136*(4), 474-479.

Ozdamar, O., & Bohórquez, J. (2008). Suppression of the Pb (P1) component of the audiotry middle latency response with contralateral masking. *Clinical Neurology, 119*, 1870-1880.

Pavlovcinova, G., Jakubikova, J., Trnovec, T., Lancz, K., Wimmerova, S., Sovcikova, E., & Palkovicova, L. (2010). A normative study of otoacoustic emissions, ear asymmetry, and gender effect in healthy schoolchildren in Slovakia. *The International Journal of Pediatric Otorhinolaryngology, 74*(2), 173-177.

Picton, T. W. (2011). Middle-Latency Responses: The Brain and the Brawn. In *Human Auditory Evoked Potentials* (pp. 247-284). Abingdon, Oxfordshire, UK: Plural Publishing.

Porter, R. J., & Berlin, C. I. (1975). On interpreting developmental changes in the dichotic right-ear advantage. *Brain and Language, 2*, 186-200.

Prakash, H., Abraham, A., Rajashekar, B., & Yerraguntla, K. (2016). The effect of intensity on the speech evoked auditory late latency response in normal hearing individuals. *The Journal of International Advanced Otology, 12*(1), 67-71.

Ramkissoon, I., & Beverly, B. L. (2014). Auditory middle latency responses in chronic smokers compared to nonsmoker: Differential effects of stimulus and age. *Journal of Speech, Language, and Hearing Research, 57*, 271-284.

Ross, B., Herdman, A. T., & Pantev, C. (2005). Right hemispheric laterality of human 40 Hz auditory steady-state responses. *Cerebral Cortex, 15*(12), 2029-2039.

Roth, G. L., Roth, G. L., Kochhar, R. K., Kochhar, R. K., Hind, J. E., & Hind, J. E. (1980). Interaural time differences: Implications regarding the neurophysiology of sound localization. *Journal of the Acoustical Society of America, 68*(6), 1643-1651.

Scharf, B., Magnan, J., & Chays, A. (1997). On the role of the olivocochlear bundle in hearing: 16 case studies. *Hearing Research, 103*(1-2), 101-122.

Shankweiler, D., & Studdert-Kennedy, M. (1967). Identification of consonants and vowels presented to left and right ears. *The Quarterly Journal of Experimental Psychology, 19*(1), 59-63.

Sharma, A., Kraus, N., McGee, T. J., & Nicol, T. G. (1997). Developmental changes in P1 and N1 central auditory responses elicited by consonant-vowel syllables. *Electroencephalography and Clinical Neurophysiology, 104*, 540-545.

Sininger, Y. S., & Cone-Wesson, B. (2006). Lateral asymmetry in the ABR of neonates: evidence and mechanisms. *Hearing Research, 212*(1-2), 203-211.

Snihur, A. W., & Hampson, E. (2011). Sex and ear differences in spontaneous and click-evoked otoacoustic emissions in young adults. *Brain and Cognition, 77*(1), 40-47.

Snihur, A. W., & Hampson, E. (2012). Click-evoked otoacoustic emissions: response amplitude is associated with circulating testosterone levels in men. *Behavioral Neuroscience, 126*(2), 325-331.

Strelnikov, K., Rouger, J., Lagleyre, S., Fraysse, B., Deguine, O., & Barone, P. (2009). Improvement in speech-reading ability by auditory training: Evidence from gender differences in normally hearing, deaf and cochlear implanted subjects. *Neuropsychologia, 47*(4), 972-979.

Swaab, D. F. (2007). Sexual differentiation of the brain and behavior. *Best Practice & Research Clinical Endocrinology & Metabolism, 21*(3), 431-444.

Thornton, A. R. D., Marotta, N., & Kennedy, C. R. (2003). The order of testing effect in otoacoustic emissions and its consequences for sex and ear differences in neonates. *Hearing Research, 184*(1-2), 123-130.

Tremblay, K., Kraus, N., McGee, T., Ponton, C., & Otis, B. (2001). Central auditory plasticity: Changes in the N1-P2 complex after speech-sound training. *Ear & Hearing, 22*(2), 79-90.

Tsolaki, A., Kosmidou, V., Hadjileontiadis, L., Kompatsiaris, I. Y., & Tsolaki, M. (2015). Brain source localization of MMN, P300 and N400: aging and gender differences. *Brain Res, 1603*, 32-49. doi:10.1016/j.brainres.2014.10.004

Tucker, D. A. D., S.; Harris, S.; Pelletier, S. (2002). Effects of Stimulus Rate and Gender on the Auditory Middle Latency Response. *Journal of the American Academy of Audiology, 13*, 146-153.

Van Maanen, A., & Stapells, D. R. (2009). Comparison of multiple auditory steady-state responses (80 versus 40 Hz) and slow cortical potentials for threshold estimation in hearing-impaired adults. *International Journal of Audiology, 44*(11), 613-624.

Verhulst, S., Jagadeesh, A., Mauermann, M., & Ernst, F. (2016). Individual differences in auditory brainstem response wave characteristics. *Trends in Hearing, 20*. doi:10.1177/2331216516672186

Wagner, W., Frey, K., Heppelmann, G., Plontke, S. K., & Zenner, H. (2008). Speech-in-noise intelligibility does not correlate with efferent olivocochlear reflex in humans with normal hearing. *Acta Oto-Laryngologica, 128*, 53-60.

Weihing, J., & Musiek, F. (2014). The influence of aging on interaural asymmetries in middle latency response amplitude. *Journal of the American Academy of Audiology, 25*(4), 324-334.

Weihing, J., Schochat, E., & Musiek, F. (2012). Ear and electrode effects reduce within-group variability in middle latency response amplitude measures. *The International Journal of Audiology, 51*(5), 405-412.

Wible, B., Nicol, T., & Kraus, N. (2002). Abnormal neural encoding of repeated speech stimuli in noise in children with learning problems. *Clinical Neurophysiology, 113*, 485-494.

Zakaria, M. N., Jalaei, B., & Wahab, N. A. (2016). Gender and modulation frequency effects on auditory steady state response (ASSR) thresholds. *European Archives of Otorhinolaryngology, 273*(2), 349-354.