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Amplification Vs The Natural Ear: A Test On The Effectiveness Of The Natural Ear On Adults Ability To Match Pitch In Song

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DEDICATION

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AMPLIFICATION VS THE NATURAL EAR: A TEST ON THE EFFECTIVENESS OF THE NATURAL EAR ON ADULTS ABILITY TO MATCH PITCH IN SONG

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ABSTRACT

Background: Singing is a natural enjoyment of life; however, individuals tend to isolate themselves from this enjoyment due to their inability to match pitch accurately. A new technology, the *Natural Ear* provides altered auditory feedback to the user while singing. It is hypothesized that this feedback may aid in the user's ability to match pitch.

Purpose: The purpose of this study is to compare the effects of the *Natural Ear* to amplification and no amplification conditions on pitch matching accuracy in song.

Study Design: This study used a complex counterbalance within-subjects design.

Methods: 50 adults from the El Paso Metropolitan area were recruited to participate in the following study. Each participant was surveyed for their experience and emotions surrounding singing. They then were instructed to sing *Happy Birthday* or an original melody on /la/ with three different forms of auditory feedback.

Results: Inconsistent results were found regarding the effectiveness of the *Natural Ear* in increasing pitch matching accuracy in melodies in adults. This study found that utilization of any auditory feedback could assist adults in increasing pitch matching accuracy. Additionally, results indicated that practice is necessary when using the *Natural Ear* as significant improvements were seen in notes that were in the middle and end of the songs.

Conclusion:

This study found that the *Natural Ear* is effective in increasing pitch matching accuracy in song. Furthermore, this study revealed that amplification of natural voice can cause an increase in pitch matching accuracy in song. These findings indicate that altered auditory feedback, such as the *Natural Ear* and amplification of natural voice, can assist in pitch matching accuracy when compared to natural auditory feedback.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1: LITERATURE REVIEW

1.1 Introduction

Singing is a cultural, social and universal enjoyment of human life (Hutchins & Peretz, 2012); however, there are individuals who are unable to sing on pitch (Hutchins & Peretz, 2012). This inability can result in feelings of isolation during social interactions (Hutchins & Peretz, 2012). When considering how often people sing during celebrations such as birthdays, holidays or church gatherings it becomes clear how important singing can be in cultural and social aspects of life. In fact, in a study conducted by Welch et al., (2014) the researchers found that socialization through singing begins in childhood and children who were considered advanced singers were more socially included by their peers (Welch et al., 2014). So, what classifies an individual as an advanced or good singer?

A key component to the perception of an individual being a good singer is their ability to accurately match pitch (Hutchins & Peretz, 2012). Pitch is defined by Cousineau, Oxenham and Peretz (2014) as being the perceptual correlate of the rhythm of a waveform that is a major characteristic for speech and singing. Pitch matching encompasses a complex behavior between an individual's ability to perceive a pitch and then match that pitch using only their voice.

Ten to fifteen percent of the western population are affected by inaccuracy in pitch matching, whether they are singing a familiar (Dalla Bella et al., 2007) or unfamiliar song (Pfordresher & Brown, 2007). Although fifteen percent of the western population believes they are tone deaf, only about four percent are truly tone deaf (Thompson, 2007). Being tone deaf impairs an individual's perception of pitch which impairs their ability to match pitch (Bradshaw & McHenry, 2004). This can additionally be described as neural mismapping. Neural mismapping is defined by Pfordresher and Brown, (2007) as a breakdown between perception and production resulting in poor singing ability. Meaning that when a person sings a note, they perceive themselves to be on pitch; However, their production may not be on pitch and thus there is a mismatch in the perception of their vocal productions.

The present study seeks to test the efficacy of a new technology designed to alleviate the mismatch in the auditory feedback system and increase pitch matching accuracy. Auditory feedback is essential for monitoring and developing vocal control. Therefore, when there is a breakdown in this area it is difficult for individuals to regulate and monitor vocal productions (Jones & Keough, 2008). This technology hopes to provide corrected feedback to assist in repairing the neurological mismapping resulting in inaccurate pitch productions when singing.

1.2 What Makes a Good Singer?

To understand how to improve poor singers, it is important to know what makes a good singer. Singing encompasses both the physical and musical abilities of an individual. The physiological components include control and coordination of systems involved with sound production such as respiration, phonation, resonance and auditory systems to monitor vocal productions. The musical components include the ability to produce a melodic voice that follows the melody tempo while maintaining accurate pitch (Watts, Murphy, & Barns-Burroughs, 2002).

Many studies have looked at the components of singing such as pitch clarity, vocal quality and assertiveness. Some of these components can be easily measured and some are more subjective and difficult to measure (Hutchins & Peretz, 2012). However, a common finding in the literature is that the most important factor in judging singing ability is pitch accuracy (Hutchins & Peretz, 2012; Goetze, Cooper, & Brown, 1990; Joyner, 1969). In fact, in a study reported by Hutchins and Peretz (2012), music educators reported the primary component necessary of a talented singer is the ability to sing pitches accurately.

Additionally, Joyner (1969) reports three requirements to be considered a good singer. These three requirements are: 1) Be able to tell one pitch from another to gain a correct mental concept of the melodic outline. 2) Be able to recall successions of pitches in melodic patterns to be prepared for the next note. 3) Have a vocal instrument that is able to produce the target pitches of a melody with immediate and accurate responses (Joyner, 1969; Goetze, Cooper, & Brown, 1990). All three of these components include prerequisite skills necessary for accurate pitch matching.

Specifically, when discussing pitch matching accuracy, an individual's ability to monitor and adjust their fundament frequency is analyzed. Watts, Murphy, and Barnse-Burroughs (2002) state that manipulation of an individual's fundamental frequency to increase pitch matching accuracy is a key component seen in good singers. Additionally, manipulation of auditory feedback has been seen to result in changes in fundamental frequency productions of trained and untrained singers (Murry, 1990). However, trained singers reported that with the altered auditory feedback they were able to tell they were off pitch by their internal regulation. Other components that encompass a good singer are described in section 1.5. Nonetheless, the primary component necessary to be considered a good singer is accuracy in pitch matching.

1.3 Pitch Matching

As stated above, pitch matching is the primary focus when all individuals sing, both professionally and to themselves (Murry, 1990). In order to accurately match pitch, an individual must be able to hear the presented stimuli, therefore normal auditory function is required (Moore, et al., 2006). The auditory feedback loop is the primary stimuli for speech regulation. Individuals monitor their auditory feedback to produce intelligible messages to their communication partners in regular speech (Siegel & Pick, 1974). In singing, it has been found that individuals depend on their auditory feedback to increase their vocal loudness or pitch if it does not match the target stimulus. In a study conducted by Elma (1981) altering the feedback of an individual's fundamental frequency resulted in modifications to their vocal productions. Pitch matching is dependent on auditory feedback because it is used to monitor the pitch that is being produced and compares vocal productions with the stimuli being presented. This results in modifications to vocal productions until a match between vocal productions and the stimuli are found (Moore, et al., 2006).

Pitch matching can be influenced by the type of stimulus presented. Green (1987) was a pioneer in this research as she found that the use of a human model stimulus matched by age influenced pitch matching accuracy in children. This was followed by a study conducted by Moore, et al. (2006), who found the use of a recording of a person's own voice to match pitch increased accuracy in pitch matching versus other stimuli such as a female voice and a complex tone. Peter, et al. (2014) found that individuals tend to do better in accurately matching pitch when the stimulus is within their natural singing range. Additionally, if the stimulus is on the extremities of their vocal range, more difficulty is experienced (Hutchins et al., 2014).

When considering an individual's vocal range, vocal-motor control is analyzed. Vocal-motor control is defined by Jones and Keough (2008) as having control of the intrinsic and extrinsic muscles of the larynx to produce target stimulus perceived through auditory feedback. In a study conducted by Hutchins, et al. (2014) it was found that vocal motor control can impact and limit an individual's singing ability. This study stated that singing ability does not always accurately represent an individual's pitch matching abilities. With the use of another modality such as a slider or instrument the limitations of their vocal- motor control is eliminated and pitch matching accuracy is increased.

Considering the effects of vocal-motor control and the influence of stimulus items, the present study utilized human models of two different ranges to allow for optimal pitch matching conditions in participants. Additionally, since it is known that altering an individual's auditory feedback of their own fundamental frequency can result in a change in the individual's vocal productions, additional questions arise about corrected auditory feedback and the use of this in assisting individuals in increasing pitch matching accuracy in real time.

1.4 Pitch Matching Studies

Common findings related to pitch matching indicate that a person must be able to accurately perceive a target pitch before they can match the pitch. As discussed in previous sections, key components for singing on pitch include the ability to discriminate pitches, recall a melody, and maintain control of physiological factors (Joyner, 1969). Studies conducted on singers and non-singers to assess the effects of singing tasks, types of stimuli, and pitch range were reviewed for the present study.

Singing tasks can have an effect on an individual's ability to match pitch. In a study conducted by Tremblay-Chompoux, et al. (2010) it was found that non-singers made less pitch errors when imitating a model than when compared to singing from memory. Additional findings showed that singing along to a model of a familiar tune on /la/ increased the accuracy of pitch productions (Tremblay-Chompoux et al. 2010). Furthermore, Pfordresher and Brown (2007) found that individuals tended to sing poorest when trying to match pitch with an accompaniment (instrumental model). Contrarily, Hutchins, et al. (2010) states that having a model for the participant to imitate will not make any difference in the individual's ability to match pitch more accurately. Lévêque, Giovanni, and Schön (2012) found that there is a human model advantage in "poor" singers. These researchers analyzed pitch matching accuracy when singing along to a familiar tune and sustained single notes. Stimulus presented included a complex synthesized imitation of the tune/note or a real voice sample. When comparing pitch matching accuracy, 16 of the 18 "poor" singers were more accurate when singing along to the real voice samples. Additional research conducted by Granot, et al. (2013) supports that individuals are more likely to accurately match pitch with a human timber than with a synthetic timber. There are additional benefits of a live vocal stimuli in eliciting higher vocal accuracy than that of recorded vocal stimuli (Granot, et al. 2013).

When utilizing real voice samples, the age, gender, and range of the stimuli model are additional factors that can affect pitch accuracy. In a study conducted on 1st – 6th grade children who were presented adult male, adult female, and child singing models it was found that the children matched pitch more accurately to the child model than with any of the adult models (Green, 1987). In a study conducted by Peter, et al. (2014) it was found that individuals tend to match pitch better when the target frequencies are within their range. When the target frequencies are out of vocal range, they will try to match the target pitch an octave below (Peter, et al. 2014).

The present study utilized a human model of the target melodies as this timber is the most natural and has been found to increase pitch matching accuracy in poor singers (Lévêque, Giovanni, & Schön, 2012; Granot, et al. 2013). Participants were asked to sing either a familiar or unfamiliar tune on /la/ as previous research has revealed the benefits of utilizing both melody types (Dalla Bella et al., 2007; Pfordresher & Brown, 2007; Tremblay-Chompoux et al., 2010). Both female and male vocal models were utilized to allow participants to choose the model they felt was within their singing range as this would ensure optimal opportunity for pitch matching accuracy (Hutchins et al., 2014; Peter, et al., 2014). Octaves were taken into account in the analysis of the data based on research from Peter, et al., (2014). These stimulus items were utilized to provide optimal opportunities for the individuals to show their true pitch matching ability.

1.5 Theories of Pitch Matching

Although there has been a substantial amount of research conducted to examine the cause of poor pitch matching, a primary cause has not been determined. Various theories have been used to explain poor pitch matching abilities. These theories include analysis of sensorimotor skills, the feed forward and feedback control, and the neurological disconnect. These theories will be discussed in turn to explain breakdowns in auditory feedback and how the *Natural Ear* application is expected to mend these breakdowns.

A theory developed by Selleck and Sataloff (2014), breaks down two major components of the auditory system, the feedback control and the feedforward control. The feedback control allows for immediate correction of phonation using sensory information resulting in regulation of pitch when singing or speaking. The feedforward control relies more on controlling rate of speech and voice without depending on the auditory feedback and depending more on previously learned behaviors (Selleck & Sataloff, 2014).

Pfordresher and Brown (2007) suggested that there is a neural mismapping between perception and production that causes poor singing ability, instead of it being solely due to a breakdown in production or perception individually. It stands to reason that if a person cannot accurately perceive their own fundamental frequency (F_0), the resulting production will be inaccurate due to the mismapping within the action-perception network. The action-perception network is defined as the process at which perception and motor action are integrated for accurate pitch matching in singing (Pfordresher and Brown, 2007).

The neural mismapping as explained by Pfordresher and Brown (2007) is demonstrated in various special populations. Male to Female (MtF) transgender individuals need adequate feedback when targeting feminization of the voice (Gelfer, 1999). For this to be achieved, they must first perceive their produced F_0 and make adequate modifications to achieve the target F_0.

Additionally, individuals who have suffered a traumatic brain injury may have a breakdown in the auditory feedback loop resulting in poor expressive language and comprehension (Sullivan, 2010). Lastly, individuals with central auditory processing disorder (CAPD) do not have a breakdown in their auditory systems, but in the processing of speech and discriminating speech from noise (Cacace &McFarland, 1998).

The *Natural Ear* was designed to correct the breakdown between perception and production of voice when singing by providing constant automatic feedback of the singer's fundamental frequency. It is expected to increase the singer's awareness of their fundamental frequency to assist with correction and regulation of pitch productions while singing.

1.6 Altered Feedback and The *Natural Ear*

Altered auditory feedback can impact pitch matching abilities in non-singers. Altering the F_0 feedback has been predicted to result in changes in pitch productions in individuals during sustained vowel productions. Furthermore, there is evidence that neurological mechanisms rely on auditory feedback for proper pitch production and regulation.

In a study conducted by Elman (1981), participants were instructed to sustain a vowel. As they sustained the vowel, the researchers shifted the F_0 that was being fed back to the participants' ear. Results shows that non-singers experienced difficulty sustaining a constant F_0 when their feedback F_0 was shifted. In another study conducted by Burnett, Senner and Larson (1996) testing the impact of altered auditory feedback on F_0 control, participants were instructed to ignore upward and downward F_0 shifts while sustaining a vowel or singing a musical scale. This study revealed that when the F_0 was shifted upward the participants pitch decreased and when the F_0 was shifted downward the participants pitch increased. This indicates that neural mechanisms rely heavily on F_0 when controlling pitch productions. In a follow up study by Burnett, Freeland, Larson and Hain

(1998), this theory was further tested using masking, frequency shifted feedback, and duration of presentation. When analyzing the pitch productions with frequency shifted feedback it was revealed that the participants followed the same trend seen in the 1996 study (Burnett, Senner & Larson, 1996). When the F_0 was increased or decreased the participants “opposed” (produced opposite shift of pitch production from F_0 feedback) their pitch productions shifted. However, all participants had at least one instance of a “follow” (produced shame shift of pitch production as F_0 feedback) response. When looking at the masking and duration of presentation, it was concluded that pitch productions were not directly influenced by these changes in feedback. This revealed to the authors that auditory feedback is necessary for pitch control and allows for finetuning of pitch productions.

After considering the importance of auditory feedback in pitch regulation and the impact altered F_0 can have on pitch productions, it is hypothesized that in poor singers, there is a breakdown in F_0 perception resulting in a neural mismapping as explained in section 1.5. To mend the breakdown in F_0 perception and production as explained by the neural mismapping theory, Dr. Eric Freudenthal, a professor in the computer science department at the University of Texas at El Paso (UTEP), developed an app called the *Natural Ear*. The *Natural Ear* is a computer app that filters out dissonant harmonics, allowing the individual to focus on their fundamental frequency. When used with headphones, the individual singing receives real-time feedback of their F_0, which eliminates additional harmonics that can distort the perception of their pitch productions. This filter is predicted to increase the individual’s awareness of pitch productions when listening to their F_0. With an increase in awareness of pitch productions it is hypothesized that the individual will correct their pitch while singing the target melody.

1.7 Purpose of the study

This investigation was completed to examine whether utilization of the *Natural Ear* and/or amplified auditory feedback of the natural voice would result in an increase in awareness of pitch productions thus resulting in corrections and improvements of pitch accuracy. The purpose of the *Natural Ear* app is to increase the accuracy of pitch productions. To test this the app was used with individuals who self-identified as being "bad" singers to establish whether the *Natural Ear* would increase pitch production accuracy in song. This is the first study to analyze the effectiveness of the *Natural Ear* on pitch matching in song.

The research questions in the present study are as follow: (1) Can the *Natural Ear* increase accuracy of pitch matching in individuals in song? (2) Does amplified auditory feedback of the individuals own voice increase accuracy of pitch matching in song? (3) Does the *Natural Ear* increase pitch matching accuracy more than amplified auditory feedback in song?

It is hypothesized that the *Natural Ear* and the amplification conditions will both increase pitch matching accuracy in song; however, the *Natural Ear* is expected to result in greater pitch matching accuracy due to the filtration of the dissonant frequencies. The findings will potentially verify whether this product is effective in the adult population in increasing awareness of vocal pitch productions in song. If found to be effective, the *Natural Ear* could potentially be used to enhance therapeutic management and be utilized for further studies in special populations in Speech and Language Pathology.

CHAPTER 2: METHODS AND PROCEDURES

2.1 IRB Approval

The University of Texas at El Paso institutional review board for human subjects approved this study.

2.2 Study Design

This study used a counterbalance within-subject design. A convenience sample was collected and counterbalanced by assigning various order of presentation of conditions to account for treatment effects.

2.3 Screening Process and Participants

Participants were selected based on availability. A total of 50 adults were recruited by word of mouth and fliers. The presented study was conducted in a clinical treatment room at the UTEP Speech-Language and Hearing Clinic. All participants underwent a hearing screening using the American Speech Language Hearing Association guidelines for adults. The participants were presented pure tones of 1,000Hz, 2,000Hz and 4,000Hz at 25dB and were instructed to raise their hand when they heard the tone. The hearing screening was administered by a graduate student clinician or a trained undergraduate research assistant. If the participants did not pass the hearing screening they were excluded from the study. Participants received course credit for participation. Verbal consent was provided by the participants to include their audio recordings in the database for the present study.

Of the 50 participants, 34 were female between the ages of 18 and 60 years of age and 16 were males between the ages of 18 and 60 years of age. Of the 34 female participants 16 stated that they had some singing experience and of the 16 female participants two stated that they still sing and perform in public areas. Of the 16 male participants six stated they had some singing experience and three of the six reported still singing and performing in public areas. The 18 women and 10 men that stated they did not have singing experience identified as "shower singers." Shower singers are defined as individuals who enjoy singing to themselves in private in areas such as the car or shower. Table 2.1 presents the demographic information for the subject sample used in this study.

Table 2.1

Participant Characteristics- Adults from El Paso Texas Metropolitan Area

	Female	*Male*
Number of participants	34(68%)	16(32%)
Average Age	26.32 (SD=7.60, Range=21 to 55)	31.25 (SD=12.30, Range=18 to 57)
Shower Singers	18(53%)	10(62.5%)
Participants with singing experience	16(47%)	6(37.5%)

2.4 Equipment

The preliminary procedures, e.g. hearing screening, was performed in a therapy room located in the UTEP Speech, Language, and Hearing clinic. The audiometric screening was done using an Oscilla SM920-p Screening Audiometer. The pure tone stimuli were presented through Amplivox headphones. The American Speech, Language, Hearing Association hearing screening guidelines for adults were used for all participants. These guidelines state to present pure tones at 25dB for 1,000Hz, 2,000Hz and 4,000Hz (ASHA, 2017).

Stimuli for pitch matching tasks were created on a *Lenovo ideapad 100S* laptop containing the *PRAAT: Doing Phonetics by Computer* (Version 6.0.36; Phonetic Sciences, University of Amsterdam) software through a *TRITTON Kama Stereo Headset*. Two versions of *Happy Birthday* and an original melody created by Lluvia Mendiola were sung on /la/ and recorded. One sample was of a female professional singer and the other was of a male professional singer. These samples were recorded using the *PRAAT* software at a sampling rate of 44.1kHz. Each /la/ in the *Happy Birthday* recordings were analyzed in the *PRAAT software* to measure the fundamental frequencies of each note. A total of 23 frequencies from *Happy Birthday* ,13 frequencies from the male target melody and 10 frequencies from the female target melody were analyzed and recorded on a Microsoft excel sheet.

In a similar manner, each participant's voice was recorded as they sang *Happy Birthday* or the original melody on /la/ with the *PRAAT* software on a *Lenovo* laptop or an *HP Envy x360 Convertible* through the *TRITTON* headset microphone.

2.5 Feedback and Stimuli

The participants sang the target melodies with three different forms of feedback. These different feedback forms served as the three treatment conditions that were analyzed. The first condition was the individual's natural auditory feedback. This feedback form was used as a control to gather a baseline on the individual to see their pitch matching accuracy without corrective feedback. This was completed by having the participant sing *Happy Birthday* or the original melody on /la/ with one ear uncovered by the headphones to allow for natural auditory feedback.

Amplified feedback of the individuals natural voice was used as the second condition for the present study. This feedback form was assessed to examine whether amplifying an individual's natural voice would increase their awareness of pitch matching accuracy. This condition was completed with the headphones covering both ears of the participant with the amplification level set to the comfort of the participant.

The final condition used was the corrective feedback. The *Natural Ear* application, that filters out dissonant frequencies, was used to assess the effect the corrective feedback has on increasing pitch matching accuracy. This condition was completed with both ears covered by the headset and volume level tailored to the comfort of the participant.

Conditions were counterbalanced by assigning each participant different orders of presentation of conditions. Participants were assigned one of six orders of conditions listed in Table 2.2. Each sample was analyzed and compared to the target frequencies from the selected melody using the *PRAAT* software.

Table 2.2

Counterbalanced Order of Presentation of Conditions

Order Number	*First Condition*	*Second Condition*	*Third Condition*
1	Control	Amplification	*Natural Ear*
2	Control	*Natural Ear*	Amplification
3	Amplification	Control	*Natural Ear*
4	Amplification	*Natural Ear*	Control
5	*Natural Ear*	Amplification	Control
6	*Natural Ear*	Control	Amplification

2.6 Procedures

Participants were tested individually; each session lasted approximately twenty minutes. The participant was seated inside a treatment room at the UTEP Speech, Language and Hearing clinic and sat across a table from the researcher or research assistant administering the experimental protocol. A 10-question survey was administered prior to data collection, to provide background information on singing experiences, emotions, and future aspirations in singing. After the survey was conducted, randomization of the order of the feedback was used to account for order effect.

The conditions for this study were numbered as followed: (1) Control, (2) Amplification and (3) *Natural Ear*. The TRITON headset with microphone was worn during each condition; however, for the control condition participants were instructed to leave the left ear uncovered. This allowed for the participant to receive natural auditory feedback in their left ear while still receiving the stimulus in the right ear through the headset and recording into the microphone attached to the headset. The researchers instructed the participants to speak when utilizing the amplification feedback and the *Natural Ear* feedback to adjust the volume level on the headset to fit the preference of the participant. Each participant was allowed to listen to the target samples and select the version (male or female) they felt best matched their natural singing range. This allowed for the participant to perform to their optimal singing abilities. The researchers then instructed the participants to sing along to the selected version of either *Happy Birthday* or the original melody on /la/. The *PRAAT* software was used to record and analyze all vocal samples.

2.7 Analysis

After data collection, the vocal samples were analyzed and compared to the target frequencies of the melodies using the *PRAAT* software. A mini study was conducted using eleven samples (seven females, four males) collected from the 50 participants to identify the margin of error before an individual was considered off pitch. A professional singer, who identified as having perfect pitch, listened to eleven participant samples that were 2Hz, 3Hz, 5Hz, and 6Hz above or below the target frequency and identified when an individual was considered off pitch for a low(65/130Hz), middle(185/369Hz), and high (498/251Hz) frequency note. Results indicated that a +3Hz/-5Hz difference from the target frequency was considered on pitch by the professional singer. Octave differences were included in the analysis as singing an octave below or above a target frequency is considered on pitch (Peter, et al. 2014).

After the mini study, differences were calculated by subtracting the target frequency from the participants produced frequency. The researchers identified the participants as on pitch (1) or off pitch (0) by looking at the difference of each note from both the melody and *Happy Birthday*. A One- Way Repeated Measures ANOVA was used for the statistical analysis for this study. The one-way repeated measures ANOVA was used in order to compare group means and make inferences about the population means. The repeated measures ANOVA was utilized to analyze the data of the full song and individual notes. Analysis was conducted comparing all participant data and then separated to compare the data by gender. Additionally, one-way repeated measures ANOVA were conducted comparing the coded binary data (1- on pitch, 0-off pitch) by all participants and then separated and compared by gender.

CHAPTER 3: RESULTS

The study was designed to research and examine the effectiveness of the *Natural Ear* on pitch matching accuracy in adults, as well as, compare the effects of the *Natural Ear* with amplified auditory feedback of an individual's natural voice. The participant differences (target frequency subtracted by the produced frequency) for each note along with the binary data coded by the researchers were analyzed.

Initially, all the participant data was split into three conditions. The conditions were labeled as follows: (1) was the controlled condition (no altered form of auditory feedback), (2) was the amplification condition (amplified natural voice), and (3) was the *Natural Ear* condition (filtered fundamental frequency). A One-Way Repeated Measures univariant analysis of variance (ANOVA) was conducted to determine within group differences with regards to the three conditions (controlled condition (1), amplification condition (2), and *Natural Ear* condition (3)). The pitch matching accuracy constituted the dependent variable and the three conditions used in the study constituted the independent variables.

3.1 One Way Repeated Measures ANOVA Analysis

Table 3.1 consists of the results from a one-way repeated measures ANOVA comparing the differences of the individual notes and full song for *Happy Birthday* and the original melody. Statistically significant differences were found between the target and the actual production for note 15 [$F(1,50)=3.25$, $p=.047$] and note 16[$F(1,50)=4.11$, $p=.022$] of Happy Birthday, favoring the amplification condition indicating the mean of the sample differences were closer to the target note when using the amplification condition than when compared to the *Natural Ear* and control group.

Table 3.1

Differences by Target Note for All Participants

Song	Note	Target Hz	*F*	*p*	Significant Condition
HB	Note 15	180.7	3.25	.047*	Amp.
	Note 16	167.45	4.11	.022*	Amp.
Melody	NONE	NONE	NONE	NONE	NONE

Note. *=≤ .05 is Significant

Table 3.2 consists of the results from a one-way repeated measures ANOVA comparing the differences of the individual notes and full song for *Happy Birthday* and the original melody of the male participants in the study. Statistically significant differences were found between the target and the actual production for note 5 [$F(1,22)=7.42$, $p=.015$] of Happy Birthday an note 17[$F(1,16)=9.12$, $p=.003$] of Happy Birthday, favoring the *Natural Ear* condition indicating the mean of the sample differences were closer to the target note when using the *Natural Ear* condition than when compared to the amplification and control group for these particular notes. However, Statistically significant differences were found between the target and the actual production for note 6 [$F(1,16)=5.10$, $p=.025$] and the full Happy Birthday song [$F(1,16)=6.13$, $p=.002$], favoring the amplification condition indicating the mean of the sample differences were closer to the target note when using the amplification condition than when compared to the *Natural Ear* and control group for note 6 and the full song of Happy Birthday.

Results for the original melody from the one-way repeated measures ANOVA comparing the differences of the individual notes and full song of the male participants statistically significant differences were found between the target and the actual production note 4 [$F(1,16)=4.81$, $p=.019$] of the original melody, favoring the controlled condition. Statistically significant differences were found between the target and the actual production for note 8 [$F(1,16)=4.79$, $p=.019$] and the full original melody [$F(1,16)=3.92$, $p=.020$], favoring the amplification condition. Indicating the mean of the sample differences were closer to the target note without feedback for note 4 in the original melody and with amplification for note 8 and the full melody.

Table 3.2

Differences by Target Note of Male Participants

Song	Note	Target Hz	*F*	*p*	Significant Condition
HB	Note 5	127.5	4.78	.029*	NE
	Note 6	130.8	5.10	.025*	Amp.
	Note 17	149.9	9.12	.003*	NE
	Full	All	6.13	.002*	Amp.
Melody	Note 4	108.7	4.81	.019*	Cont.
	Note 8	123.1	4.79	.019*	Amp.
	Full	All	3.92	.020*	Amp.

Note. *=≤ .05 is Significant*

Table 3.3 consists of the results from a one-way repeated measures ANOVA comparing the differences of the individual notes and full song for *Happy Birthday* and the original melody of the female participants in the study. Statistically significant differences were found between the target and the actual production for note 16 [*F (*1,34) =3.55, *p*=.039] and the full Happy Birthday song [*F* (1,34) =3.53, *p*=.029] favoring the amplification condition. Indicating the mean of the sample differences were closer to the target note when using the amplification condition than when using to the *Natural Ear* and control group for note 16 and the full Happy Birthday song.

Table 3.3

Difference by Target Note of Female Participants

Song	Note	Target Hz	*F*	*p*	Significant Condition
HB	Note 16	167.45	3.55	.039*	Amp.
	Full	All	3.53	.029*	Amp.
Melody	NONE	NONE	NONE	NONE	NONE

Note. *=≤ .05 is Significant

Table 3.4 consists of the results from a one-way repeated measures ANOVA comparing the differences of the individual notes and full song for *Happy Birthday* and the original melody by the order of presentation of the *Natural Ear*. Statistically significant differences were found between the target and the actual production when the *Natural Ear* was presented first, for note 16 [*F (*1,16) =4.80, *p*=.042] from *Happy Birthday*, favoring the *Natural Ear* condition. When the *Natural Ear* was presented first, statistically significant differences were found between the target and the actual production for the full *Happy Birthday* song [*F (*1,16) =5.35, *p*=.005], favoring the amplification condition. Lastly, when the *Natural Ear* condition was presented first, statistically significant differences were found between the target and the actual production the full original melody [*F (*1,16) =4.15, *p*=.020], favoring the controlled condition.

When the *Natural Ear* was presented last, statistically significant differences were found between the target and the actual production for note 5 [*F (*1,22) =9.00, *p*=.005] and note 22[*F (*1,22) =4.54, *p*=.039] from *Happy Birthday*, favoring the *Natural Ear* condition. Statistically significant differences were found between the target and the actual production for note 23 [*F (*1,50) =3.90, *p*=.026] and the full *Happy Birthday song* [*F (*1,22) =6.16, *p*=.000], favoring the amplification condition. Lastly, when the *Natural Ear* was presented last, statistically significant differences were found between the target and the actual production for note 12 [*F (*1,22) =4.52, *p*=.039], favoring the controlled condition. These results indicate that order of presentation of the *Natural Ear* did not influence effectiveness of the *Natural Ear* on accuracy of pitch productions.

Table 3.4

Difference Order of Presentation of Natural Ear (NE)

Order of Condition	Song	Note	Target Hz	*F*	*p*	Significant Condition
NE First	HB	Note 16	167.45	4.80	.042*	NE
	HB	Full	All	5.35	.005*	Amp.
	Melody	Full	All	4.15	.020*	Cont.
NE Last	HB	Note 5	263.5	9.00	.005*	NE
	HB	Note 12	262.8	4.52	.039*	Cont.
	HB	Note 22	401	4.54	.039*	NE
	HB	Note 23	360	5.11	.029*	Amp.
	HB	Full	ALL	8.16	.000*	Amp.

Note. *=≤ .05 is Significant*

Table 3.5 consists of the results from a one-way repeated measures ANOVA comparing the binary data of the individual notes and full song for *Happy Birthday* and the original melody. Statistically significant differences were found between the target and the actual production for note 14 [*F (*1,50) =3.90, *p*=.026] of *Happy Birthday*, favoring the *Natural Ear* and amplification condition. In the original melody, statistically significant differences were found between the target and the actual production for Note 9 [*F (*1,50) =3.37, *p*=.045] for both the *Natural Ear* condition and the amplification condition.

Table 3.5

Binary Data by Target Note All Participants

Song	Note	Target Hz	*F*	*p*	Significant Condition
HB	Note 14	222.4	3.90	.026*	NE
Melody	Note 9	257.4	3.37	.045*	NE and Amp.

*Note. *=≤ .05 is Significant*

Table 3.6 consists of the results from a one-way repeated measures ANOVA comparing the binary data of the individual notes and full song for *Happy Birthday* and the original melody by the order of presentation of the *Natural Ear*. Results found that when the *Natural Ear* was presented first, there was not a significant difference between the conditions.

When the *Natural Ear* was presented last, statistically significant differences were found between the target and the actual production for note 7[F (1,22) =5.17, p=.022] of *Happy Birthday*, favoring the *Natural Ear* and amplification condition. Statistically significant differences were found between the target and the actual production for note 8 [F (1,22) =7.42, p=.015] of *Happy Birthday*, favoring the *Natural Ear* condition. Lastly, statistically significant differences were found between the target and the actual production for note 12 [F (1,22) =7.42, p=.015] of the original melody, favoring the amplification condition. These results further indicate that order of presentation of the *Natural Ear* did not influence the effectiveness of the *Natural Ear* on accuracy of pitch productions.

Table 3.6

Binary Data of Presentation of Natural Ear (NE)

Order of Condition	Song	Note	Target Hz	*F*	*p*	Significant Condition
NE Last (1-2-3)	HB	Note 7	300.3	5.71	.022*	NE and Amp.
2-1-3	HB	Note 8	268	7.42	.015*	NE
	Melody	Note 12	145.1	7.42	.015*	Amp.

*Note. *=≤ .05 is Significant; Condition 1= Control, Condition 2= Amplification, Condition 3= Natural Ear*

CHAPTER 4: DISCUSSION

The purpose of present study was to evaluate the efficacy of the *Natural Ear* in assisting individuals to accurately match pitch when singing. This study aimed to evaluate the efficacy of the *Natural Ear* compared to normal amplified auditory feedback and natural auditory feedback (controlled group). To restate the research questions, the investigator hoped to answer the following questions: (1) Can the *Natural Ear* increase accuracy of pitch matching in individuals in song? (2) Does amplified auditory feedback of the individual's own voice increase accuracy of pitch matching in song? (3) Does the *Natural Ear* increase pitch matching accuracy more than amplified auditory feedback in song? Addressing these issues will help clinicians learn the efficacy of the *Natural Ear* in improving individual's ability to accurately match pitch.

A notable finding in this study is that with the *Natural Ear* there were significant increases in all individual's ability to accurately match pitch in nine notes. This follows the prediction that the *Natural Ear* would increase awareness of fundamental frequency productions resulting in corrections and an increase in accuracy in pitch matching. Additionally, results showed significant improvement in accuracy in pitch matching using the amplification condition for 14 notes. This can be attributed to the increase in self-awareness of the individuals natural voice and is consistent with previous findings of the human model advantage by Leveque, Giovanni and Schön (2012).

Overall the findings of the following study were inconclusive. Though there was significance found for nine notes using the *NE* condition, there were 14 significant notes found for the amplification condition. Furthermore, the notes that were found to be significant for the *NE* condition were in the middle and the end of the melodies. This led researchers to believe that the individual may need time to practice using the *NE* to familiarize themselves with the filtered feedback.

This study demonstrates the effectiveness of utilizing altered auditory feedback on pitch matching accuracy. This study supports the belief that altered auditory feedback can assist in mending the breakdown in the feedback control. The mend in the feedback control done by providing a corrected stimulus to the individual resulted in accurate feedforward productions (Selleck & Sataloff, 2014). Since the *Natural Ear* can provide the feedback to individuals in real time, it can be especially beneficial for those who desire to sing and want the benefits of the corrected auditory feedback immediately. However, these findings must be interpreted with caution as further research is needed to test the true effectiveness of the *NE*.

4.1 Limitations

The results of this study should be interpreted with caution as there are limitations. One being the individuals singing range. Before starting the testing procedures, the researchers did not establish a natural range for each participant. Some individuals tend to have a wider singing range than others. It is important to keep in mind that all participants were presented the same recording of *Happy Birthday* or the melody based on gender only and not on singing range.

The present study did not consider all components of voice. The human voice encompasses many components such as resonance, loudness, intensity, and pitch. Improvements in vocal quality were perceptually noted by researchers when listening to participants singing using the *Natural Ear* feedback; however, this was not always reflected in the frequencies produced by the individual. Further studies should include analysis of other components of the human voice to allow for an in depth understanding of the changes perceived in the singer's voice that were not reflected when analyzing frequency alone.

The melodies that were created by Lluvia Mendiola encompassed notes from the pentatonic scale. The melody created, shifted from high notes to low notes in the scale. When assessed by a professional singer, it was discovered that the melody created was difficult because both the rhythm and pitches were not considered to have a natural flow. Since most individuals in this study were not trained singers, this was considered a difficult task for them to follow both the rhythm of the melody and match pitch. Therefore, in future studies, researchers should consider utilizing melodies that are easier for the singer to follow.

Additional limitations include the presentation of stimuli. The presentation of *Happy Birthday* and the original melody was a recording of a female/male professional singer and not a live vocal stimulus. However, benefits were found when the stimulus presented was live versus when the stimulus was presented in a recording (Granot, et al. 2013). The recorded stimulus was more practical for the purpose of this study.

Lastly, a limitation related to the *Natural Ear* app was the latency response of the feedback. Since the software is newly developed, there are some inconsistencies with the feedback time. There can be a slight latency that can affect an individual's ability to self-monitor their pitch and results in an echo feeling.

4.2 Future Work

This research is a small milestone for the future of the Speech and Language Pathology profession. With the knowledge of the efficacy of the *Natural Ear* in increasing accuracy in pitch matching, Speech and Language Pathologists can begin to utilize this device in special populations. This corrected auditory feedback does not have to be limited to singing and performing.

The benefits of the corrected auditory feedback allow an individual to hear and regulate their fundamental frequency. This can be beneficial to multiple special populations in this field. Further research can be done in the transgender male to female (MtF) populations working on vocal feminization since this population needs to focus on increasing and sustaining a higher fundamental frequency (Gelfer, 1999). By using the *Natural Ear,* which allows the individual to hear their fundamental frequency, it can be predicted that an increase in regulation and monitoring of fundamental frequency productions can result in accurate production of target frequencies in speech.

Further research should additionally implement the *Natural Ear* in individuals with central auditory processing disorder. Central auditory processing disorder is a disorder that is not a result in the breakdown in the auditory system but in the pathways leading from the auditory stimuli up to the central nervous system (Cacace &McFarland, 1998). The *Natural Ear* may assist these individuals by increasing awareness of their own vocal productions as well as the vocal productions of individuals around them. Bypassing the brains filtration of speech and background noise and focusing primarily on speech.

Additional populations to study using the *Natural Ear* include individuals who have suffered a traumatic brain injury. Research has shown that individuals who suffer from a traumatic brain injury have difficulty with speech perception, comprehension and vocal regulation (Sullivan, 2010). The *Natural Ear* could assist these individuals by providing them real time feedback of their fundamental frequency allowing them to regulate and correct vocal productions.

4.3 Conclusion

Singing is a natural enjoyment of life; however, individuals tend to isolate themselves from this enjoyment due to their inability to match pitch accurately. The purpose of this study was to analyze the efficacy of the *Natural Ear* software in increasing accuracy of pitch matching when compared to natural auditory feedback and amplified auditory feedback. This study found that the *Natural Ear* is effective in increasing pitch matching accuracy in song. Furthermore, this study revealed that amplification of natural voice can cause an increase in pitch matching accuracy in song. These findings indicate that altered auditory feedback, such as the *Natural Ear* and amplification of natural voice, can assist in pitch matching accuracy when compared to natural auditory feedback.

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VITA

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She has participated as a volunteer research assistant in the Augmentative and Alternative Communication Laboratory at the University of Texas at El Paso under the direction of Dr. Vannesa Mueller for four years. During this time, she has had the privilege of presenting a poster titled "Signing at Daycare: Prevalence of Sign use and Reduction in Stress Levels" at the 2017 Texas Speech Language Hearing Association Annual Convention at Fort Worth Texas. She has additionally presented a poster at the 2018 American Speech Language Hearing Association in Boston Massachusetts titled "Can't Match Pitch? Never Fear, Use the True Ear!"

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