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The Effectiveness Of The Natural Ear On Adults Ability To Accurately Match Pitch

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Dedication

I would like to dedicate this research to my husband, Roman Rosales, and daughter, Leilani Rosales. Roman, you are my rock. Your constant love, support, sacrifice, and belief in me helped me to realize my dreams. Leilani, I wanted to show you what it means to follow your dreams. Thank you for always making me laugh, for your thoughtfulness, love, and understanding, especially on those late nights when I couldn’t be there to tuck you in and kiss you goodnight. I love you both with all of my heart! I couldn’t have done this without you. Thank you for your sacrifice and helping me realize my dream of becoming a Speech-language pathologist.

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Abstract

Background: Many theories, such as oral motor, perceptual, and sensorimotor deficits, have been posited to explain inaccurate pitch matching abilities. The current study identifies with the sensorimotor deficit theory and found it to be the most plausible explanation for inaccurate singing abilities. The Natural Ear (NE) program was designed to process voice productions in real-time and filter out the discordant harmonics, allowing a person to hear only their F_0.

Purpose: The purpose of this study was to examine the effectiveness of the Natural Ear program in increasing pitch matching accuracy in singers.

Methods: A total of 50 participants were included in the study; fourteen men and thirty-six women, ages 18-57. Female participants matched vocal tones presented via headset in the keys of C4, F#4, and B4. Male participants matched vocal tones presented via headset in the keys of C3, F#3, and B3. Three conditions were administered in random order to each participant: normal auditory feedback (NAF), Amplification of their voice (AMP), and the NE.

Results: As a group, participants were more accurate without any additional feedback when compared by target note and gender. However, males demonstrated increased pitch matching accuracy with amplification across all target notes, indicating additional auditory feedback was helpful. When the NE was presented second or last, the participants demonstrated increased accuracy with amplification when matching the target note C. In addition, singers were more accurate when using the NE across all target notes when the NE condition was presented last, indicating additional practice may affect pitch matching accuracy.

Discussion: It is still unknown if the NE will result in more accurate pitch matching over amplification. However, based on the results of the current study it can be assumed that any additional auditory feedback may result in more accurate pitch matching abilities. Clinicians should consider using additional auditory feedback when working with patients who have difficulty regulating pitch and intonational patterns.

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Chapter 1: Review of the Literature

Music has been argued to be one of the most influential and fundamental aspects of a person's life (Hallam, 2010); this is true whether they are listening, writing, or singing the music. Music is made using a variety of different instruments, but the most significant instrument may be the human voice. Unfortunately, there remains a disconnect for many in their ability to sing in tune. Ten to fifteen percent of the western population are affected by inaccuracy in pitch matching, whether they are singing a familiar song (Dalla Bella et al., 2007) or trying to match the pitch of an unfamiliar tone (Pfordresher & Brown, 2007). There are many factors that are considered when labeling someone as an accurate or inaccurate singer. When music educators were asked what factors have the greatest effect on a person's ability to sing well, they stated that intonation (ability to match pitch) was a deciding factor (Watts et al., 2003). Furthermore, despite popular belief about timing inaccuracies, most errors that occur in untrained singers are related to pitch (Dalla Bella et al., 2007). A person must be able to accurately perceive a target pitch before they can match the pitch. The ability to discriminate pitches, recall a melody, and maintain control of physiological factors are necessary for singing in tune (Joyner, 1969). In a previous study by Joyner (1969) that compared singers and monotone singers, a significant difference in the singer's ability to discriminate between pitches and remember tunes was found but the cause remains unknown.

WHAT IS THE CAUSE OF POOR SINGING?

The primary functions of the phonatory and articulatory systems are life support and nutrition intake, whereas the secondary functions allow for speech production. Proper adjustment of the vocal register allows for modifications to intonation and ability to change pitch. There are special populations, such as those with Parkinson's disease, autism, central auditory processing disorder, and transgender individuals, who have difficulty with intonation patterns (American Speech Language Hearing Association, 2005; Darkins, Fromkin, & Benson, 1988; Nadig & Shaw, 2012; Thornton, 2008). However, these difficulties are typically not a concern for the majority of the U.S. population who have the ability to control and manipulate their vocal register with relative ease during speech, and yet, some are still unable to sing in tune. According to the National Institute on Deafness and Other Communication Disorders, only 5% of Americans have difficulty using their voice (What Is Voice? What Is Speech? What Is Language?, 2017) and the majority of these have difficulty due to laryngeal nerve damage caused by an accident, surgical procedure, viral infection, or cancer. However, this does not account for the other 5-10% of the population that cannot sing in tune. It is logical to question what causes poor pitch matching abilities in the typical adult. Many theories have been posited to explain this phenomenon, some of which are deficits in motor control, pitch perception, and sensorimotor mapping errors.

Motor Deficits

One of the explanations for poor pitch matching is a deficit in production abilities. Joyner (1969) and Cleall (1970) hypothesized that the inability to accurately match pitch was not due to perception but rather production. Despite a person's physical ability to reach a note, if a poor singer does not have good control of their vocal apparatus they will be unable to produce notes reliably (Hutchins & Peretz, 2012). For example, a person may be able to swing a bat but that does not guarantee that they will be able to hit a baseball. A study by Joyner (1969), found that children identified as "real monotone" singers, showed improvement in accurate vocal productions after vocal-motor training. The children's ability to perceive their own production as correct increased over time. Joyner proposed that vocal training was the most effective way of "breaking the deadlock between voice and mind" and stated that pitch discrimination may improve as a result of greater vocal-motor control.

Few studies have investigated the direct relationship between motor productions and pitch perception. As a result, a study by Hutchins and Peretz (2012) aimed to assess whether a person's inability to match pitch was related to auditory perception or vocal production. To do this, participants were instructed to match a pitch using a slider, as well as with their voice. If participants could match pitch using the slider but not with their voice, the deficit could be attributed to a deficit in motor control and not perception. If the participant could not match the tone with a slider or produce the target tone, the cause was more likely due to a deficit in auditory perception. Overall, participants were able to accurately match the target pitch presented, using the slider. However, participants were considerably less accurate when using their voice. The results are consistent with previous studies (Dalla Bella et al., 2007; Pfordresher & Brown, 2007) and support the hypothesis that poor pitch matching may be attributed to deficits in motor control and not pitch perception.

Perceptual Deficits

By far, the most widely researched theory to explain inaccuracy in pitch matching has concerned perceptual deficits. It stands to reason that if a pitch is perceived incorrectly, the resulting production will also be incorrect. The perceptual deficit hypothesis suggests that the inability to match pitch is solely due to inaccurate perception, rather than a lack of physical ability. A study by Bradshaw and McHenry (2005), determined to establish whether a relationship between pitch discrimination ability and vocal production ability was present in inaccurate singers. Among inaccurate singers, it was found that some could accurately perceive pitch while others could not. All were unable to accurately produce the target pitches. Although no relationship was found, it is unclear whether poor pitch perception plays a role in inaccurate pitch production because of the differences observed between groups.

According to Hutchins and Peretz (2012), although most researchers have investigated perceptual pitch matching abilities using discrimination tasks that require participants to identify whether a pitch is on or off target, a limited number of studies have measured pitch perception thresholds. This is a limitation in the current research since tasks that require discrimination of same or different stimuli (percent correct) cannot be directly correlated to vocal pitch accuracy (deviation in cents) due to differences in measurement (Hutchins & Peretz, 2012). To add to the issue, there is no clearly defined threshold for vocal pitch accuracy. For example, one study found that a deviation in 5 cents indicates a just noticeable difference in pitch (Zwicker & Fastl, 1999).

Another study found that a note needed to deviate more than 50 cents by untrained musicians and more than 30 for trained musicians to be considered out of tune (Hutchins & Peretz, 2012). Yet another study used a measurement of +/- 100 cents (+/- 1 semitone) for determining out of tune pitch matching (Dalla Bella et al., 2009; Dalla Bella et al., 2007; Pfordresher & Brown, 2007). Despite the variation, a few studies have measured pitch perception thresholds but the validity of the results should be interpreted with caution due to the lack of definitive psychoacoustic measures.

In saying this, Zarate et al. (2010) examined the relationship between deficits in perception and accuracy in pitch matching. A pretest was administered requiring participants to identify differences in pure-tone and vocal-tone micromelodies that varied by cents, match simple pitches vocally, and match melodic pitches during a singing task. The experimental group received pitch discrimination training and the control received no training. They hypothesized that if a person could be trained to perceive and discriminate small differences in pitch, then an increase in vocal pitch matching accuracy would also be noted. After training, auditory discrimination skills were significantly enhanced for pure tone and vocal-tone micromelodies when comparing control and experimental groups. However, no significant difference was noted in vocal pitch matching abilities. These results were similar to findings reported by Bradshaw and McHenry (2005), Dalla Bella et al. (2007), and Pfordresher and Brown (2007). Each of these studies observed good auditory perception skill in inaccurate singers.

Sensorimotor Deficits

As a result of their research findings, a new hypothesis termed sensorimotor account was proposed by Pfordresher and Brown (2007) to provide a better explanation for poor singing skills. They suggested that there was a mismapping between perception and production that causes poor singing ability, instead of it being solely due to a breakdown in production or perception. This theory is well grounded because of the inconsistent evidence to date. More recently, researchers have focused on determining the cause of poor singing in relation to the sensorimotor theory.

Studies using brain imaging (Brown et al., 2004; Perry et al., 1999; Riecker et al., 2000) have identified areas of the brain that are activated during singing tasks. In addition to the primary and secondary auditory cortices, the primary motor cortex, supplementary motor area, frontal operculum (including Broca's area), the insular cortex, posterior cerebellum, and the basal ganglia are also employed. Therefore, it is reasonable to assume that proper functioning and communication within the auditory-motor network is necessary to match pitch. During singing, the auditory stimuli must be correctly encoded and vocal productions need to be accurately monitored by the feedback loop for needed adjustments. Singing in tune is an ongoing process and is determined by the accuracy in which one's fundamental frequency (F_0) is produced and adjusted to match an intended pitch (Elliott & Niemoeller, 1970). When singing, it has been suggested that one must be able to perceive and control their F_0 (Titze, 1994) to be considered an accurate singer.

In saying this, auditory feedback is necessary and plays an important role in proper control of F_0, to include corrections in phonation using sensory information. When trying to explain auditory feedback, three roles have been posited (Jones & Keough, 2008). The first role is to provide information about vocal stimuli, which allows for corrections in pitch, volume and resonance. Second, it provides information about the environment that might impact the effectiveness of the vocal production, resulting in a need to articulate with greater precision or change the rate of speech. Lastly, it aids in the generation of internal models that allow for preparation of the vocal tract and related structures necessary for speech. Researchers (Elliott & Niemoeller, 1970; Ward & Burns, 1978) have found that when there is breakdown that results in a lack of auditory feedback, necessary adjustments to F_0 do not occur, reducing a person's ability to accurately match pitch. Other studies found that if a person's F_0 was altered and played back into the ear, they would adjust their pitch to compensate for the mismatch by increasing their volume or the duration of their utterances (Bauer et al., 2006; Larson et al., 2000; Burnett et al., 1998; Burnett et al., 1997; Laukkanen, 1994; Elman, 1981; Lane & Tranel 1971).

Furthermore, Watts et al. (2003) aimed to determine whether there was a difference in pitch matching accuracy between trained singers (TS) and untrained singers with natural talent (UTS) and no talent (NTS), when auditory feedback was altered. In the external feedback condition, the stimuli were presented through a loud speaker at 70 dB SPL and the participants were asked to match the pitch. During the internal feedback condition, the participants were asked to match the tones presented via loud speaker at 70 dB SPL, while a masking noise was played through a pair of headphones. Overall, results showed that the TS and UTS groups were more accurate at matching pitch. When the groups were expected to rely solely on internal feedback, the UTS group was more accurate than the TS group. However, the UTS and NTS groups were both more accurate at matching pitch during the internal feedback condition, in comparison to the TS group who were less accurate. The authors suggested that this difference was due to the emphasis placed on "training the ear," during vocal training, to monitor vocal productions. In comparison, Jones and Keough (2008) found that singers relied more on internal feedback for production of F_0. More importantly, Watts et al. (2003) found that untrained singers with expressed talent are just as accurate as trained singers when matching pitch. A singer with natural talent is said to be someone who can sing in tune but has not received formal training. Additionally, natural talent is thought to be related to the following: ability to accurately perceive pitch, coordinate perception with motor systems to reproduce the pitch, and monitor the output. However, it is still unclear why some untrained singers can accurately match pitch and others cannot.

To further investigate this phenomenon, Loui et al. (2009) examined the brain activity of normal and tone-deaf individuals while taking part in a pitch discrimination task. The brain has a fiber tract known as the arcuate fasciculus (AF) that connects the temporal and frontal brain regions. A structured MRI with diffuser tensor imaging and tractography was used during the task to pinpoint regions of interest in the endpoints of the AF in each hemisphere, which allowed identification of structures being utilized during the pitch discrimination tasks. The study found that in normal individuals, the superior and inferior AF was easily identified but in tone-deaf individuals only the inferior AF could be seen. In addition, tone-deaf individuals had an overall decrease in fiber volume, resulting in an impaired action-perception network because of a disruption in the AF structure. It was found that the volume in the superior AF was responsible for a person's conscious pitch discrimination and the inferior AF volume determined the degree of action-perception mismatch in any one individual. Furthermore, when analyzing the images, a decrease in volume was found in individuals that were severely tone-deaf and only slightly tone-deaf, enabling generalization of the findings to the normal population of individuals with poor pitch perception and/or poor pitch production abilities. Thus, supporting the sensorimotor hypothesis stating that poor pitch production is due to a neural mismapping between what is perceived and what is produced.

THE INVENTION OF THE NATURAL EAR AND IT'S PURPOSE

The Natural Ear ® (NE) was invented by Dr. Eric Freudenthal, a professor in the Computer Science department at The University of Texas at El Paso (UTEP), to compensate for the neural mismapping that occurs in inaccurate singers (Freudenthal, Hanson, & Usevitch, 2017). It stands to reason that if a person cannot accurately perceive their own F_0, the resulting production will be inaccurate due to the mismapping within the action-perception network. The NE program was designed to process voice productions in real-time and filter out the discordant harmonics. In a matter of milliseconds, the participants F_0 is played back, allowing them to correct their pitch. As a result, the person would then be able to adjust and correct their F_0 to match the desired pitch.

The purpose of this study was to examine the effectiveness of the NE in increasing pitch matching accuracy in inaccurate and accurate singers. We hypothesized that a significant difference would be found when comparing pitch matching abilities between amplification and NE conditions, where the NE condition resulted in greater accuracy during vocal tasks. Also, in accordance with Loui et al. (2009), by providing a means of correction for the neural mismapping that occurs in inaccurate singers, an overall increase in accuracy should be observed in both accurate and inaccurate singers.

This study aimed to answer the following questions:

1. Will amplification alone aid in pitch matching ability by increasing a person's self-awareness of their own voice?

2. Will the NE increase pitch matching accuracy by providing an accurate perception of their F_0 during production?

Chapter 2: Methods

Design

This experiment employed a complex counterbalanced within-subjects design with 3 independent variables. The variables were normal auditory feedback (control), amplified auditory feedback, and the NE feedback. The dependent variable was the participants' ability to match pitch. This design was beneficial in that it allowed the experimenters to control for errors in individual differences; each person was exposed to all conditions and served as their own control. Another drawback can be seen in order and carryover effects, in which the order of the treatments may potentially affect the other and the preceding treatment may carry over to the proceeding treatment resulting in inaccurate outcomes. To control for order and carryover effects, the order in which the conditions were presented were randomized, using the online random number generator *randomizer.us*, ensuring that if there was an effect it would be found.

Participant Screening Process

Adequate hearing is necessary for any task requiring auditory input, therefore a hearing screening was completed on all participants to ensure hearing was within normal range. The screening was administered by either a graduate student clinician or a trained research assistant. The hearing screening was presented monaurally with headphones at 25 dB HL per ASHA recommendations for adults. The frequencies tested were 1000Hz, 2000Hz, and 4000Hz. The time required to administer the hearing screening was around 4 minutes and the screening was administered in a quiet room in the Speech, Language and Hearing Clinic at the University of Texas at El Paso (UTEP). To pass, the participant was required to acknowledge each frequency by raising their hand in a minimum of two out of three trials per frequency.

The hearing screening was used as an exclusionary criterion for participation in the study. Fifty persons responded to advertisements or were invited to participate by an experimenter or previous participant. Of the fifty persons screened, all passed the hearing screenings and were included in the study.

PARTICIPANTS

The experimenters recruited potential participants by randomly asking students and faculty on campus to participate in the study. Participants were also recruited by word of mouth from persons who had previously participated in the study. In addition, advertisements were placed around campus and posted on social media.

Fourteen men and thirty-six women, ages 18-57, were included in the study. All participants came from a variety of social and ethnic backgrounds. Participants varied in their singing ability and previous participation in singing acts. People often under or overestimate their singing ability (Pfordresher & Brown, 2007), preventing specific recruitment of accurate and inaccurate singers. Consequently, all singers were classified as accurate or inaccurate based on the data collected from the control condition. The study was approved by the University of Texas at El Paso's International Review Board and all participants provided verbal consent for participation and audio recording. Participants were informed that no personal identifying information would be revealed to the public. Some participants received course extra credit for their involvement in the study.

MATERIALS

Stimuli

Studies have found that pitch matching accuracy increases when human voice is used as the target stimuli in comparison to synthetic recordings (Leveque et al., 2011), pure tones, and piano tones (Granot et al., 2013). According to Granot et al. (2013), there is no significant difference in a live voice model versus a recorded voice model. Furthermore, a study by Duvvuru and Erickson (2016) found that the presence or absence of vibrato, in a voice model, does not affect a person's ability to match pitch accurately. As a result, recorded voice models were chosen to ensure continuity in the pitch and presentation of the stimuli and to alleviate any scheduling conflicts that might arise using a live voice model.

The target keys for the stimuli were provided by an experienced music professor and were representative of the average singing range for male and female individuals. The male tones were digitally recorded using Praat by a trained male singer with 40 years of experience at C3 (130.81 Hz), F#3 (174.6 Hz), and B3 (246.9 Hz), respectively. The female tones were digitally recorded using Praat by a trained female singer with 10 years of experience at C4 (261.63 Hz), F#4 (369.9 Hz), and B4 (498.8 Hz). All tones were recorded with the production of /a/ for approximately 4 seconds. Each tone produced by the trained singers was analyzed to ensure that the desired target frequencies had been accurately matched.

Instrumentation

The participants sat at a table with three chairs in a well-lit clinic room. The participants sat on one side of the table, facing the examiners on the other side of the table. An Oscilla SM920-P Screening Audiometer was placed to the right of the participant on the table during the hearing screening and was removed after. On the left side of the table, a Lenovo ideapad 100S was used by the examiners to run the Praat program, the NE program (with and without filtering), access the web-based survey, and play the pre-recorded stimuli. In addition, a Kama, over the ear stereo headset with an attached microphone, was plugged into the Lenovo ideapad 100S and used to present the stimuli for all conditions. On a small table adjacent to the main table, a 2011 Apple MacBook Air was used to audio record the sessions.

PROCEDURES

Each participant was seated at a table in a quiet room in the Speech, Language and Hearing Clinic at UTEP. After passing a hearing screening, the experimenters asked each participant a series of 10 questions from a survey pertaining to their experiences and feelings about singing (refer to the appendix for a complete list of survey questions). Next, the experimenters explained that three (as mentioned above) tones would be administered via the head set for each condition. Each participant was instructed to match the tone with their voice, to the best of their ability, for 3-4 seconds.

The order of the conditions varied due to randomization. For the control (normal auditory feedback) condition, each participant was instructed to leave one side of the headphones off, exposing an ear for external auditory feedback during production, and to sing into the headset's microphone. For the NE and amplification conditions, participants were instructed to place the headphones on both ears and sing into the microphone. Amplification was provided as another independent variable to discern whether the increase in pitch matching was due to the NE or the additional auditory feedback.

The Praat *doing phonetics by computer* program (Version 6.0.31) was used to record all voice samples, to later determine the mean pitch value of each tone. All sound recordings were saved and uploaded to a password protected Google Drive with a "P" for participant, the number depicting the order in which they participated, the condition, and the note being matched. For example: participant 10 doing the NE condition in note C4, would be labeled as "P10 NE C4". No identifying information was used during labeling and storing of the data.

SCORING AND RELIABILITY

The tones, produced by each participant, were displayed on a spectrogram using the Praat program and were analyzed for mean pitch. Only the stable portion of each tone was measured and no less than two seconds were analyzed per tone. In lieu of the conflicting research attempting to provide a clearly defined criterion for determining pitch accuracy, a new criterion was set based on a single-subject analysis. The rater was a trained singer and vocal coach with more than 40 years-experience. To determine the rater's perceptual accuracy, the target notes were played in random order requiring the rater to identify the note and key presented auditorily. The rater perceptually identified the notes with one-hundred percent accuracy. The rater was presented with randomly selected samples from the current study and instructed to first state the target key and then determine whether it was on/off pitch. The perceptual analysis revealed the following criterion. A maximum deviation of 3.9 Hz above the intended pitch and 5.5 Hz below the intended pitch was deemed as perceptually accurate.

To assess intra-rater reliability for analysis of mean pitch, the examiner randomly selected 10 (20%) participants samples to reanalyze. When comparing the original scoring with the second scoring, the intra-rater agreement between scores was 94%. Intra-rater reliability resulted in a high agreement between the first and second scores, indicating the results were reliable.

Chapter 3: Results

A total of 50 adults participated in the study, including 14 men and 36 women, ages 18-57. All participants came from a variety of social and ethnic backgrounds. Participants varied in their singing ability and previous participation in singing acts. All participants took part in a survey pertaining to their experiences and feelings about singing. The results of the survey are as follows: 42% (4 M; 17 F) of participants reported singing in an organized group, 24% reported singing karaoke (3 M; 9 F), 60% reported negative feelings associated with singing in public or around others, and 94% expressed a desire to sing better. As stated previously, participants were rated as on or off pitch based on the control condition. The following is the percentage of participants who accurately matched pitch by note: C=56%, F=50%, and B=34%. A steady decrease in accuracy was noted as the target frequency increased. In addition, 42% were accurate across two consecutive tones and only .08% of the participants were accurate across all tones, indicating the majority of participants were inaccurate singers.

Group differences

A one-way repeated measures analysis of variance (ANOVA) was applied to the pitch-matching data to determine if there was a significant difference between condition means. The level of significance was set at <0.05. Conditions were first compared by target note and gender. The results are as follows: data for female participants matching the target note C were approaching significance (F = 2.57, p = .083) for the control condition, combined data from males/females matching the target note C were approaching significance (F = 2.76, p = .067) for the control, males matching the target note B were approaching significance (F = 3.02, p = .066) for the control condition, and males approached significance (F = 2.67, p = .074) across all target notes for amplification. To determine if there was a practice effect, the order in which the NE was presented was analyzed by gender. The results are as follows: there was a significant effect (F = 4.29, p = .023) for the amplification condition when the NE was presented last for the target note C, the amplification condition approached significance (F = 2.82, p = .072) when the NE was presented second for the target note C, and the NE condition approached significance (F = 2.73, p = .075) when presented last across all target notes.

Table 1

Comparison of Condition by Target Note and Gender

Target Note	Gender	*F*	*p*	Significant Condition
C	Female	2.57	.083*	Cont.
	Male/female	2.76	.067*	Cont.
B	Male	3.02	.066*	Cont.
All	Male	2.67	.074*	Amp.

Note. * = $\leq$ .099 is considered approaching significance.

Table 2

Order of Presentation of Natural Ear (NE) for Males and Females

Order of Conditions	Note	*F*	*p*	Significant Condition
NE Second	C	2.82	.072**	Amp.
NE Last	C	4.29	.023*	Amp.
	All	2.73	.075**	NE

Note. * = $\leq$ .05 is significant. ** = $\leq$ .099 is considered approaching significance.

Chapter 4: Discussion

The purpose of this study was to examine the effectiveness of the NE in increasing pitch matching accuracy. A survey was completed by all participants pertaining to their experiences and feelings about singing. As previously stated, music may be one of the most influential and fundamental aspects of a person's life (Hallam, 2010), which includes singing. This was consistent with our survey results, where 94% of participants indicated their desire to sing better. Although 42% of all participants reported singing in an organized group, a greater number (60%) reported having negative feelings associated with singing in public, indicating that 18% of people singing in groups were not confident in their singing abilities. In addition, data analysis revealed that of the participants who reported the ability to sing and were currently singing or had previously sang in an organized group, all were accurate across two consecutive notes without additional feedback, contradicting reported findings by Pfordresher and Brown (2007) stating that people often under or overestimate their singing ability. Despite accurate identification of singing ability, these participants still reported negative feelings associated with singing, which was more likely due to a limited understanding of their vocal range. Slightly more than half of singers (56%) were accurate when matching pitch to note C with natural auditory feedback. However, this accuracy decreased as the note increased. Likewise, prior to additional auditory feedback, only .08% of participants were on pitch across all tones. Although the stimulus tones were selected based on the typical female and male vocal ranges, variation in vocal registers was expected due to anatomy, physiology, and singing ability.

WAS AMPLIFICATION HELPFUL?

One of the questions this study aimed to answer was, "Will amplification alone aid in pitch matching ability by increasing a person's self-awareness of their own voice?". It is reasonable to assume that as self-awareness of voice productions increases, an increase in pitch matching abilities would also be seen. Auditory feedback is necessary and plays an important role in proper control of F_0, to include corrections in phonation using sensory information (Jones & Keough, 2008), which is consistent with the current findings. Participants were more accurate on average when provided with additional auditory feedback in the form of amplification. However, Loui et al.'s (2009) claim that amplification does not correct the mismapping that is said to occur between perception and production should still be considered relevant. Although the current study results favored amplification when conditions were compared by order of presentation, it is unknown whether lasting effects on pitch matching accuracy occurred.

WAS THE NATURE EAR EFFECTIVE?

This study also sought to answer whether the NE would increase pitch matching accuracy by providing an accurate perception of their F0 during production. At first glance, as a group, participants were more accurate without any additional feedback when compared by target note and gender. However, males demonstrated increased pitch matching accuracy with amplification across all target notes, indicating additional auditory feedback was helpful. Further analysis was performed to exam the effects of randomization, if any, on the participants pitch matching accuracy. The results indicated that participants were more accurate with additional practice. When the NE was presented second or last, the participants demonstrated increased accuracy with amplification when matching the target note C. In addition, singers were more accurate when using the NE across all target notes when the NE condition was presented last, indicating additional practice may affect pitch matching accuracy. This provides support for the study by Loui et al. (2009), stating that inaccuracies in pitch matching may be due to a sensorimotor deficit, in which a neural mismapping occurs in inaccurate singers. It stands to reason, that for the inaccurate singers who can differentiate between pitches but are unable to accurately match pitch themselves, a mismapping is occurring due to the inaccurate perception of their own voice. Although it is yet unknown whether the NE will result in remapping of neural pathways due to the limited practice time and duration of target tones, it can be said that some form of additional auditory feedback is beneficial in increasing pitch matching accuracy. This provides additional support for previous studies (Bauer et al., 2006; Larson et al., 2000; Burnett et al., 1998; Burnett et al., 1997;

Laukkanen, 1994; Elman, 1981; Lane & Tranel, 1971) findings that alterations to the frequency of vocal productions results in changes to F_0. Instilling the necessity of accurate feedback in production and manipulation of F_0.

LIMITATIONS AND FUTURE RESEARCH:

A limitation of the current study was the lack of training/practice time. All data was gathered during one session and the short duration of the single tones may not have provided adequate time for correction of their F_0. A study by Watts et al. (2003) suggested that the difference in pitch matching accuracy between trained and untrained singers was due to the emphasis placed on "training the ear," during vocal training, to monitor vocal productions. Based on the current research findings, it would be pertinent to look at the long-term effects of the NE to determine whether the NE will result in more accurate pitch matching and remapping of the neural pathways.

Another limitation was the choice of stimuli. Although target notes were chosen based on the average male and female vocal ranges, individual anatomy, physiology, and vocal range varies. With this in mind, some of the target notes were outside of the participants vocal range, negatively impacting results. The limitations in vocal registers cannot be corrected through the use of amplification or the NE alone, which may have negatively impacted results due to the lack of statistically significant differences.

Lastly, the effects of aging on vocal productions were not taken into consideration when recruiting participants. Aging results in a loss of elasticity and changes in the length and volume of the vocal folds, resulting in a reduction of pitch in women and an increase in pitch in men (Sapienza & Ruddy, 2016). In an attempt to determine whether the NE would result in positive changes for all participants despite age, age was not controlled for. As a result, participants ranged from 18-57 years of age. However, the normal effects of aging may have resulted in pitch differences confounding the overall results, due to additional limitations in vocal pitch range.

Future research should explore the effectiveness of the NE with training in a longitudinal study. This will allow for correction of the neural mismapping, if one truly exists, and provide additional evidence that inaccurate pitch matching results from sensorimotor deficits.

CLINICAL IMPLICATIONS

Singing is not an area that speech-language pathologists (SLP's) provide intervention, so why then is this research important to the field of study? Singing is a complex task, requiring considerable control of the laryngeal system. If pitch matching accuracy can be increased through the use of additional or modified auditory feedback, it is reasonable that effects will be seen in connected speech. As mentioned previously, there are special populations that struggle with pitch perception and the regulation of intonational patterns. Among these populations are those with Parkinson's Disease, Autism Spectrum Disorder, central auditory processing disorder, and transgender individuals.

According to the American Parkinson's Disease Association, it is widely known that Parkinson's Disease (PD) is a motor disorder affecting the body's functioning and dexterity. However, the cognitive deficits that manifest for some are not as commonly known. One area of cognition that is affected is the use of language and production of speech. In those with PD, it is typical to hear what is characterized as "soft speech, in which it is difficult to regulate their intonation patterns (pitch). The specific reason for this is unknown, but one can assume that if cognitive function is impaired, a sensorimotor deficit would also be present. In addition, those with autism and central auditory processing disorder (CAPD), also have deficits in cognitive functions that result in inconsistent intonational patterns. If this is the case, it stands to reason that additional or modified auditory feedback might allow for better regulation of pitch/ intonation patterns during speech in those affected by PD, autism and CAPD.

One of the newer areas of practice for the field of SLP is working with transgender clients. Transgender females are more likely to seek SLP services for voice feminization than transgender males are for voice masculinization. Transgender males do not typically need voice therapy because of the effect testosterone has on the larynx, resulting in a lower F_0. However, for transgender females, hormone therapy will not change the anatomy of the larynx, which is why much of the research to date focuses on voice therapy for transgender females. Furthermore, if they have difficulty matching pitch, it will be difficult to perceive, match, and produce the intended F_0 during therapy. Considering the results of the current study, it is plausible to assume that any feedback, whether through amplification or the NE, may have the potential to provide additional support needed during voice feminization therapy.

CONCLUSION

The current study examined the effectiveness of the Natural Ear in increasing pitch matching accuracy in inaccurate and accurate singers. It is still unknown whether the NE will result in more accurate pitch matching over amplification. However, based on the results of the current study it can be assumed that any additional auditory feedback may result in more accurate pitch matching abilities. This is consistent with previous studies (Elliott & Niemoeller, 1970; Ward & Burns, 1978) findings indicating that when there is breakdown that results in a lack of auditory feedback, necessary adjustments to F_0 do not occur, reducing a person's ability to accurately match pitch. Clinicians should consider using additional auditory feedback when working with patients who have difficulty regulating pitch and intonational patterns.

References

American Speech-Language-Hearing Association. (2005). (Central) auditory processing disorders.

Bauer, J. J., Mittal, J., Larson, C. R., & Hain, T. C. (2006). Vocal responses to unanticipated perturbations in voice loudness feedback: An automatic mechanism for stabilizing voice amplitude. *The Journal of the Acoustical Society of America,119*(4), 2363-2371. doi:10.1121/1.2173513

Bella, S. D., Deutsch, D., Giguère, J., Peretz, I., & Deutsch, D. (2007). Singing proficiency in the general population. *The Journal of the Acoustical Society of America,121*(2), 1182-1189. doi:10.1121/1.2427111

Bella, S. D., Giguère, J., & Peretz, I. (2009). Singing in congenital amusia. *The Journal of the Acoustical Society of America,126*(1), 414-424. doi:10.1121/1.3132504

Borden, G. J. (1979). An interpretation of research on feedback interruption in speech. *Brain and Language,7*(3), 307-319. doi:10.1016/0093-934x(79)90025-7

Bradshaw, E., & Mchenry, M. A. (2005). Pitch Discrimination and Pitch Matching Abilities of Adults who Sing Inaccurately. *Journal of Voice,19*(3), 431-439. doi:10.1016/j.jvoice.2004.07.010

Brown, S., Martinez, M. J., Hodges, D. A., Fox, P. T., & Parsons, L. M. (2004). The song system of the human brain. *Cognitive Brain Research,20*(3), 363-375. doi:10.1016/j.cogbrainres.2004.03.016

Burnett, T. A., Senner, J. E., & Larson, C. R. (1997). Voice F0 responses to pitch-shifted auditory feedback: a preliminary study. *Journal of Voice,11*(2), 202-211. doi:10.1016/s0892-1997(97)80079-3

Burnett, T. A., Freedland, M. B., Larson, C. R., & Hain, T. C. (1998). Voice F0 responses to manipulations in pitch feedback. *The Journal of the Acoustical Society of America,103*(6), 3153-3161. doi:10.1121/1.423073

Cognitive Impairment | American Parkinson Disease Assoc. (n.d.). Retrieved November 1, 2017, from https://www.apdaparkinson.org/what-is-parkinsons/symptoms/cognitive-changes/

Darkins, A. W., Fromkin, V. A., & Benson, D. F. (1988). A characterization of the prosodic loss in Parkinson's disease. *Brain and Language, 34*(2), 315-327.

Duvvuru, S., & Erickson, M. (2016). The Effect of Timbre, Pitch, and Vibrato on Vocal Pitch-Matching Accuracy. *Journal of Voice,30*(3), 378.e1-378.e12. doi:10.1016/j.jvoice.2015.05.011

Elliott, L. L., & Niemoeller, A. F. (1970). The Role of Hearing in Controlling Voice Fundamental Frequency. *International Audiology,9*(1), 47-52. doi:10.3109/05384917009071993

Elman, J. L. (1981). Effects of frequency-shifted feedback on the pitch of vocal productions. *The Journal of the Acoustical Society of America,70*(1), 45-50. doi:10.1121/1.386580

Freudenthal, E. A., Hanson, E. M., & Usevitch, B. E. (2017). *U.S. Patent Application No. 15/362,147*.

Granot, R. Y., Israel-Kolatt, R., Gilboa, A., & Kolatt, T. (2013). Accuracy of Pitch Matching Significantly Improved by Live Voice Model. *Journal of Voice,27*(3), 390.e13-390.e20. doi:10.1016/j.jvoice.2013.01.001

Hallam, S. (2010). The power of music: Its impact on the intellectual, social and personal development of children and young people. *International Journal of Music Education, 28*(3), 269-289.

Hutchins, S. M., & Peretz, I. (2012). A frog in your throat or in your ear? Searching for the causes of poor singing. *Journal of Experimental Psychology: General,141*(1), 76-97. doi:10.1037/a0025064

Jones, J. A., & Keough, D. (2008). Auditory-motor mapping for pitch control in singers and nonsingers. *Experimental Brain Research,190*(3), 279-287. doi:10.1007/s00221-008-1473-y

Joyner, D. R. (1969). The monotone problem. *Journal of Research in Music Education,17*, 115-124.

Lane, H., & Tranel, B. (1971). The Lombard Sign and the Role of Hearing in Speech. *Journal of Speech Language and Hearing Research,14*(4), 677. doi:10.1044/jshr.1404.677

Larson, C. R., Burnett, T. A., Kiran, S., & Hain, T. C. (2000). Effects of pitch-shift velocity on voice F0 responses. *The Journal of the Acoustical Society of America,107*(1), 559-564. doi:10.1121/1.428323

Laukkanen, A. (1994). Artificial Pitch Changing in Auditory Feedback as a Possible Method in Voice Training and Therapy. *Folia Phoniatrica et Logopaedica,46*(2), 86-96. doi:10.1159/000266297

Loui, P., Alsop, D., & Schlaug, G. (2009). Tone Deafness: A New Disconnection Syndrome? *Journal of Neuroscience,29*(33), 10215-10220. doi:10.1523/jneurosci.1701-09.2009

Lévêque, Y., Giovanni, A., & Schön, D. (2012). Pitch-Matching in Poor Singers: Human Model Advantage. *Journal of Voice,26*(3), 293-298. doi:10.1016/j.jvoice.2011.04.001

Nadig, A., & Shaw, H. (2012). Acoustic and perceptual measurement of expressive prosody in high-functioning autism: Increased pitch range and what it means to listeners. *Journal of Autism and Developmental Disorders, 42*(4), 499-511.

Perry, D. W., Zatorre, R. J., Petrides, M., Alivisatos, B., Meyer, E., & Evans, A. C. (1999). Localization of cerebral activity during simple singing. *NeuroReport,10*(16), 3453-3458. doi:10.1097/00001756-199911080-00035

Pfordresher, P. Q., & Brown, S. (2007). Poor-Pitch Singing in the Absence of "Tone Deafness". *Music Perception: An Interdisciplinary Journal,25*(2), 95-115. doi:10.1525/mp.2007.25.2.95

Free Random Number Generator. (n.d.). Retrieved October 01, 2017, from http://randomizer.us/

Riecker, A., Ackermann, H., Wildgruber, D., Dogil, G., & Grodd, W. (2000). Opposite hemispheric lateralization effects during speaking and singing at motor cortex, insula and cerebellum. *NeuroReport,11*(9), 1997-2000. doi:10.1097/00001756-200006260-00038

Sapienza, C., & Ruddy, B. H. (2016). *Voice disorders*. Plural Publishing.

Selleck, M. A., & Sataloff, R. T. (2014). The Impact of the Auditory System on Phonation: A Review. *Journal of Voice,28*(6), 688-693. doi:10.1016/j.jvoice.2014.03.018

Titze, I. R. (1994). *Principles of voice production*. Upper Saddle River, NJ: Prentice Hall.

Tourville, J. A., Reilly, K. J., & Guenther, F. H. (2008). Neural mechanisms underlying auditory feedback control of speech. *NeuroImage,39*(3), 1429-1443. doi:10.1016/j.neuroimage.2007.09.054

Ward, W., & Burns, E. (1978). Singing without auditory feedback. *Journal of Research in Singing,1*, 24-44.

Watts, C., Barnes-Burroughs, K., Andrianopoulos, M., & Carr, M. (2003). Potential factors related to untrained singing talent: a survey of singing pedagogues. *Journal of Voice,17*(3), 298-307. doi:10.1067/s0892-1997(03)00068-7

Watts, C., Murphy, J., & Barnes-Burroughs, K. (2003). Pitch Matching Accuracy of Trained Singers, Untrained Subjects with Talented Singing Voices, and Untrained Subjects with Nontalented Singing Voices in Conditions of Varying Feedback. *Journal of Voice; Official Journal of the Voice Foundation,17*(2), 185-194. doi:10.1016/s0892-1997(03)00023-7

What Is Voice? What Is Speech? What Is Language? (2017, September 07). Retrieved October 15, 2017, from https://www.nidcd.nih.gov/health/what-is-voice-speech-language#vsl_01

Zarate, J. M., Delhommeau, K., Wood, S., & Zatorre, R. J. (2010). Vocal Accuracy and Neural Plasticity Following Micromelody-Discrimination Training. *PLoS ONE,5*(6). doi:10.1371/journal.pone.0011181

Zwicker, E., & Fastl, H. (1999). *Psychoacoustics: Facts and models*. Berlin, Germany: Springer-Verlag.

Appendix

Survey Questions	
Apparent Gender:	
Age:	
1. Do you sing?	
2. Where do you sing?	
3. With whom?	
4. When do you sing?	
5. Where have you sang before?	
6. Why did you stop?	
7. How do you feel when you sing in front of people and why?	
8. Do you wish you sang better?	
9. How would it change you if you could sing better, what you do?	
10. Does it bother you if someone is singing off tune?	

Vita

Kendra Rosales obtained her certification in Deaf Studies from El Paso Community College, with a focus in sign language interpreting. She is currently pursuing a Master of Science Degree in Speech-Language Pathology. Kendra was a part of Dr. Jeffrey Olimpo's research aiming to determine the best teaching methods to provide maximal gain and retention of information/coursework. In addition, she was a part of Dr. Vanessa Mueller's AAC Lab investigating the implementation and use of baby sign on stress levels of daycare workers and presented the research findings at the 2017 Texas Speech-Language Hearing Association (TSHA) conference. Kendra was also afforded the opportunity to present her thesis research findings at the 2018 American Speech-Language Hearing Association (ASHA) conference.

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