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The Effects of Altered Auditory Feedback on Speech Production in Adults: A Comparison of Perturbation and Sensorimotor Adaptation Paradigms

Danielle S. Jacobson
Wilfrid Laurier University, danielle.s.jacobson@gmail.com

The Effects of Altered Auditory Feedback on Speech Production in Adults:

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Danielle Sophie Jacobson

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Abstract

Auditory feedback (AF) plays a crucial role in the acquisition and maintenance of fluent speech. AF allows speakers to monitor and correct for errors in their speech production and also plays an important role to create and maintain the sensorimotor relationships that support vocal motor control. To investigate the importance of AF for these functions, participants are typically exposed to brief, unexpected changes to their AF as part of a frequency altered feedback (FAF) perturbation paradigm, or persistent and predictable changes to their AF as part of a FAF adaptation paradigm. Although responses elicited from both the FAF perturbation and FAF adaptation paradigms have been used to assess the way speakers process and use AF for speech motor control, it is currently unclear whether these responses are regulated in the same manner. To investigate this research question we altered the fundamental frequency (F0) of speakers' AF while they produced vocalizations in both a FAF perturbation and a FAF adaptation paradigm. Changes in the speakers' F0 in response to the AF manipulations in each paradigm were measured. Correlational analyses were then conducted to assess whether speakers' responses showed similar patterns across the two paradigms. There was no significant relationship observed between compensatory responses or vocal variability across paradigms. This means that AF may not be used in the same way for different situational demands.

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AAF: Altered Auditory Feedback

DIVA: Directions into the Velocities of the Articulators

EEG: Electroencephalography

F0: Fundamental Frequency

FAF: Frequency Altered Feedback

LSD: Least Significant Difference

PSR: Pitch Shift Reflex

RM- ANOVA: Repeated Measured Analysis of Variance

SD: Standard Deviation

Introduction

One uniquely human trait is the capacity for communication through speech, which allows for complex social interaction. In order to speak fluently, it is necessary to monitor speech to ensure that it is intelligible (Guenther, 2006; Guenther & Vladusich, 2012). Humans are able to monitor their speech through sensory feedback, perhaps most importantly auditory feedback, which allows fluent speech to be maintained across different environments (Guenther, 2006; Guenther & Vladusich, 2012; Perkell et al., 1997; Scheerer & Jones, 2012). However, since we are also able to produce fluent speech when we cannot hear ourselves speak, it is clear that vocal production is not strictly dependent on auditory feedback (Guenther, 2006; Lane & Tranel, 1971). For example, we are still able to correct vocal errors, even when our speech is masked by loud sounds, like at a rock concert. Similarly, our speech processing system allows us to adjust our pitch in order to sing on key while we hear many other voices sing other notes simultaneously in a choir. Thus, individuals have the ability to produce fluent speech with, or in the absence of, sensory feedback across diverse contexts.

The DIVA model, a neurocomputational model of speech production and perception (Guenther, 2006), as well as experimental evidence (Hawco & Jones, 2009; Jones & Keough, 2008; Jones & Munhall, 2005; Scheerer & Jones, 2012, 2014) suggest that fluent vocal production is supported by two mechanisms: a feedback mechanism and a feedforward mechanism. The feedback mechanism relies on sensory feedback, such as auditory and somatosensory feedback (Burnett et al., 1997, 1998; Liu et al., 2011; Scheerer & Jones 2012, 2014), while the feedforward mechanism relies on sensorimotor representations (Civier et al., 2010; Guenther, 2006; Guenther & Vladusich, 2012). These two mechanisms work together to produce fluent speech. To accommodate different situational demands, the feedback and feedforward mechanisms are weighted differently during vocal production (Guenther, 2006; Guenther & Vladusich, 2012; Perkell et al., 1997). For example, when the feedback system is weighted more heavily than the feedforward system, the speech system relies more on incoming sensory information to correct for errors (Guenther, 2006; Scheerer & Jones, 2012, submitted). However, when the feedforward mechanism is weighted more heavily than the feedback mechanism, the speech system relies less on sensory feedback and more on stored sensorimotor representations for the production of speech (Guenther, 2006; Hawco & Jones, 2009; Jones & Keough, 2008; Scheerer & Jones, submitted).

One way previous studies have investigated the importance of the feedback mechanism for fluent vocal production is through the use of the frequency-altered auditory feedback (FAF) perturbation paradigm (Burnett et al., 1997; Burnett et al., 1998; Liu et al., 2011; Scheerer & Jones 2012, 2014). During a FAF perturbation paradigm (PP) speakers hear their voice shifted either up or down in frequency. These pitch shifts are introduced mid-utterance and are brief and intermittent. The brief and intermittent nature of the pitch perturbations does not allow participants to prepare their vocal responses. Thus, the responses observed are presumed to be the result of feedback-driven processes. On the other hand, the feedforward mechanism is often studied through the use of the FAF adaptation paradigm (Civier et al., 2010; Guenther, 2006; Guenther & Vladusich, 2012; Keough, Hawco & Jones, 2013). In the FAF adaptation paradigm (AP), participants hear their voice shifted from the onset of their utterances and the pitch-shift persists throughout the entire vocalization, and across many utterances. The persistent nature of the altered feedback allows participants to learn or ‘adapt’ to the new sensorimotor relationship (Guenther, 2006; Guenther & Vladusich, 2006; Keough & Jones, 2008; Scheerer & Jones, 2014).

Although both the FAF perturbation and FAF adaptation paradigms investigate the response of the speech motor system to altered auditory feedback that is perceived as vocal errors, it is currently unclear whether these responses are related within an individual speaker. Moreover, the responses recorded from these paradigms have been shown to be extremely variable from speaker to speaker. In order to fully understand speech motor control it is important to investigate whether feedback driven and feedforward driven responses are related, and how individual differences cause the feedback and feedforward mechanisms to be weighted differently across contexts. With that in mind, the aim of this thesis is to explore the relationship between the responses elicited by the two auditory feedback paradigms most cited in the literature: the FAF perturbation and the FAF adaptation paradigms.

Auditory Feedback

When speakers articulate, their brain receives sensory information regarding their motor movements. The sound that a speaker hears while they speak is referred to by researchers as auditory feedback. Fluent vocal production relies on auditory feedback, which provides a means for the speaker to monitor and thus correct for errors in their speech (Burnett et al., 1997; Liu et al., 2011). Speech is constantly monitored with the use of auditory feedback in order to control the fundamental frequency (F0; perceived as vocal pitch), as well as other aspects of the speech signal, such as intensity (Siegel et al., 1976) and formant frequencies (Guenther, 2006; Guenther & Vladusich, 2012). The importance of auditory feedback for speech motor control is highlighted by the fact that children who are born deaf often do not attain fluent speech due to their inability to monitor their auditory feedback (Cowie et al, 1982). In addition to being necessary for the development of fluent speech (Meier, 1991), auditory feedback has been shown to be important over the course of one's lifetime. For example, adults who become deaf later in life often are not able to maintain precise speech (Waldstein, 1990). Research on post-linguistic deafness has also shown that although F0 control is affected immediately after the loss of hearing, the precision of formant frequency control can be preserved for many years (Perkell et al., 1997). This pattern of findings suggests that auditory feedback is used to regulate the many aspects of speech, such as F0 and formant frequency, differently.

Previous experimental research on the use of auditory feedback for both F0 and formant frequency control has found that it is important for immediate error correction and to establish and maintain sensorimotor representations of speech sounds (Burnett, Senner & Larson, 1997; Guenther, 2006; Guenther & Vladusich, 2012; Jones & Keough, 2008; Larson, Burnett & Kiran, 2000; Meier, 1991; Scheerer & Jones, 2012). As previously mentioned, auditory feedback is thought to play a crucial role in both feedback and feedforward control of speech (Guenther, 2006; Guenther & Vladusich, 2012). With feedback control, auditory feedback is monitored on a moment-to-moment basis, and if an error is detected, a compensatory response is initiated. This cycle continues until the perceived auditory feedback is no longer erroneous (Burnett et al., 1997, 1998; Civier, 2010, Liu et al., 2011; Scheerer & Jones, 2012). The time course of the response to changes in auditory feedback is dependent on the speech parameter manipulated and the duration of the alteration. For example, when the F0 of a speaker's auditory feedback is altered suddenly and briefly, they produce rapid compensatory responses (Burnett et al., 1998; Chen et al., 2012; Guenther, 2006; Guenher & Vladusich, 2012; Hickok, 2011; Larson, Burnett & Kiran, 2000; Purcell & Munhall, 2006; Scheerer & Jones, 2014, submitted; Villacorta, Perkell & Guenther, 2007). On the other hand, when auditory feedback regarding formant frequencies is altered, speakers compensate for the perceived vocal errors over the course of successive utterances. As well, the size of the compensations to the deviant feedback is smaller than the compensations typically observed for F0 (Houde & Jordan, 1998; Houde & Jordan, 2002; Purcell & Munhall, 2006; Villacorta et al., 2007)

DIVA: A Model of Speech Motor Control

The Directions Into Velocities of Articulators (DIVA) model has been an influential neurocomputational model of speech production and perception for the past decade (Civier et al., 2010; Guenther, 2006; Guenther & Perkell, 2004; Guenther & Vladusich, 2012; Villacorta, Perkell & Guenther, 2007). Simulations performed using the DIVA model have provided testable hypotheses for how the feedback and feedforward control systems support fluent speech production. More specifically, simulations performed using the DIVA model have allowed researchers to make predictions about what will happen if vocal errors occur during speech production, and to understand how vocal articulators are controlled (Civier et al., 2010; Guenther, 2006).

The DIVA model theorizes that when a speech sound is produced, the relationship between the motor commands used to produce the speech movements and the sensory consequences of those motor commands are encoded in a sensorimotor representation (Guenther, 2006; Guenther & Vladusich, 2012). These sensorimotor representations are postulated to be stored within a speech sound map located in Broca's area (Civier et al., 2010; Guenther, 2006; Guenther & Vladusich, 2012). Activated sensorimotor representations in the brain stimulate motor commands to be sent to the motor cortex in order to control the articulators involved in the production of the intended speech sound (Guenther, 2006; Tourville et al., 2008). The movement of the speech articulators, and thus the production of speech yield auditory feedback. If there is a match between feedback from a particular speech sound and the sensorimotor representation that was stimulated, the connection is reinforced and speech continues without error. When mismatches between the intended motor output and the incoming sensory feedback are detected the posterior superior temporal gyrus is activated and corrective motor commands are generated (Guenther, 2006; Tourville et al., 2008). As well, the relationship between motor commands and their consequent sensory feedback is updated so that future errors do not occur. Thus, the next time that particular speech sound is produced, auditory feedback and the sensorimotor representation that corresponds with it in the speech sound map should match. If the feedback does indeed match the intended production, the remapped connection between these motor commands and the expected auditory feedback becomes strengthened. In this manner, sensorimotor connections are constantly remapped and strengthened in order to avoid the repetition of vocal errors and to produce fluent speech supported by feedforward control.

When a vocal production error occurs or an individual's auditory feedback is artificially altered to simulate a speech error, individuals change the way they articulate their vocalization to compensate for the error (Burnett et al., 1997, Elman, 1981). The DIVA model makes predictions about the use of auditory feedback for error correction in vocal productions, and for motor planning, in order to produce fluent speech. The feedback mechanism is used to correct for speech errors, whereas the feedforward mechanism is used to increase the reliability of speech by taking errors from auditory feedback into consideration in order to remap sensorimotor representations (Guenther, 2006; Civier et al., 2010). The DIVA model emphasizes that the feedback system and the feedforward system must work in conjunction for the production of fluent and reliable speech (Guenther, 2006).

Weighting Feedback and Feedforward Inputs

The DIVA model posits that sensorimotor representations become stronger and more well entrenched when motor commands consistently result in the same sensory consequences (Guenther, 2006; Guenther & Vladusich, 2012). That is, repeated vocal productions without perceived vocal errors leads to strengthened connections between motor commands and their sensory consequences (Guenther & Vladusich, 2012; Scheerer

& Jones, submitted). If sensorimotor connections have been reinforced many times, then presumably the sensorimotor representations can reliably produce error-free speech (Guenther, 2006; Guenther & Vladusich, 2012). Under these conditions feedforward input into speech motor control may be more heavily weighted relative to feedback input. Although a reduced weighting of feedback input may reduce the influence of incoming auditory feedback, when discrepancies between feedback and the intended motor output are detected, the weighting may be rapidly adjusted to allow the sensorimotor representations to be updated. Reliance on feedback control may be more frequent during speech development (Callan et al., 2000) or when learning a new language (Guenther, 2006; Guenther & Vladusich, 2012). However, continued reliance on auditory feedback for moment-by-moment error correction would cause motor instabilities due to the inherent delay involved in processing sensory feedback and then making the appropriate motor corrections (Burnett et al., 1997; Civier, 2010; Guenther, 2006; Hawco & Jones, 2009; Perkell, 2012; Scheerer & Jones, submitted). Thus, once the new connection is mapped, the speaker continues to use feedforward control to ensure fluent speech is produced. The feedback and feedforward mechanisms therefore work in tandem to correct for errors and produce fluent speech, even though how they are weighted changes based on situational demands (Guenther, 2006; Guenther & Vladusich, 2012; Perkell, 2012; Scheerer & Jones, 2014).

Frequency Altered Feedback (FAF)

Although both the FAF perturbation and FAF adaptation paradigms manipulate auditory feedback, the research questions that have been addressed with each paradigm have been different. The assumption made when using the PP is that the brief and unexpected changes to a speaker's auditory feedback forces speakers to rely more heavily on feedback control as opposed to feedforward control (Hawco et al., 2009). On the other hand, entire utterances are altered for a number of successive productions in the AP, and research questions typically revolve around the remapping of sensorimotor representations due to the repetitive exposure to perceived vocal errors. The hypothesized remapping of the sensorimotor representations allows for the investigation of how auditory feedback is used by the feedforward control system to avoid future vocal errors (Guenther, 2006; Burnett, McCurdy & Bright, 2008; Scheerer & Jones, submitted).

Although the focus of this thesis is on speech motor control, it should be noted that the role of sensory feedback has been extensively investigated for other types of motor behaviours. A review by Kalveram (1993) discussed the many similarities in fundamental control features that have been uncovered for speech and arm movements. For example, Scheidt, Dingwell and Mussa-Ivaldi (2001) observed motor learning in an arm-reaching task. They had participants make arm-reaching movements that were goal directed. They found that participants adapted the movement of their arm based on perturbations imposed on them. Interestingly, participants did not counteract the perturbations within a particular trial. Instead they responded similarly to how participants respond vocally in a AP, such that feedback from previous trials was used to update their motor commands in order to avoid making the same motor errors in future trials (Scheidt, Dingwell & Mussa-Ivaldi, 2001). Thus, understanding how feedback is processed for speech motor control can inform the understanding of the motor system as a whole.

Perturbation

As previously discussed, one method used to assess the importance of auditory feedback for the regulation of ongoing speech is the PP. Although early studies introduced single, brief perturbations during participants' utterances, more recent studies (e.g., Bauer & Larson, 2003; Scheerer, Behich, Liu & Jones, 2013; Scheerer, Liu, & Jones, 2013; Scheerer & Jones, 2014) have introduced deviant auditory feedback multiple times after vocalization onset. Because portions of the vocalization are shifted and returned to their original non-shifted pitch, the participant hears multiple errors within a single utterance. Thus, the voice is unstable due to the perturbations within this paradigm, which should cause the participant to rely more heavily on feedback to try to regulate and stabilize their vocal productions (Burnett et al., 1997).

Within the PP, the participant produces many vocalizations that are typically a vowel sound, such as an /a/ sound. Each vocalization is then sent to a digital signal processor, which shifts the F0 of the vocalization in real time. The altered vocalization is then immediately presented back to the participant via headphones (Burnett et al., 1997; Elman, 1981). The altered auditory feedback presented to the participant elicits an automatic compensatory response, called the pitch shift reflex (PSR; Bauer & Larson, 2003) that opposes the FAF (Burnett et al., 1997, 1998; Scheerer & Jones, 2012, 2014). The magnitude of the compensation, the time it takes for a participant to initiate the response, and the time it takes for a participant to reach maximum compensation are primary measures in studies that involve FAF perturbations. These measures can reveal how auditory feedback is weighted when vocal errors are detected by the speech motor system.

Since the PP artificially introduces errors into the participant's normal vocalization, the participant's response is to correct these errors online using feedback. The compensatory response to the altered auditory feedback generally has a much smaller magnitude compared to the magnitude of the synthetic shift (Burnett et al. 1997; Liu et al., 2011; Scheerer et al, 2013; Scheerer & Jones, 2014). These partial responses suggest that there is another mechanism at play that aids in regulating and processing speech (Burnett et al., 1997, 1998; Liu et al., 2011; Scheerer et al., 2013). If auditory feedback was the only mechanism used, one might expect that speakers would produce complete compensatory responses since the only information available to regulate speech would be auditory feedback (Burnett et al., 1997, 1998; Liu et al., 2011; Scheerer et al., 2013; Hain et al., 2000). It is predicted by DIVA and other speech models (Hickok et al., 2011) that partial responses occur because of the influence of feedforward input (Burnett et al., 1997, 1998; Guenther, 2006; Guenther & Vladusich, 2012; Liu et al., 2011; Scheerer et al., 2013). Thus, the incomplete compensation to FAF supports the notion that speech motor control relies on the combined efforts of feedforward and feedback input.

Recent evidence suggests that feedback and feedforward input are weighted differently when vocal errors are predictable, relative to when they are unpredictable. Scheerer and Jones (2014) presented participants with deviant auditory feedback that was either predictable or unpredictable in magnitude. They found that unpredictable auditory feedback resulted in larger compensatory responses than predictable auditory feedback. From this, Scheerer and Jones (2014) suggested that exposure to FAF perturbations that were predictable in magnitude resulted in heavier reliance on the feedforward mechanism. It was suggested that this was because when participants were presented with deviant auditory feedback that was predictable in magnitude, it was easier to differentiate the external perturbations from the speech they were producing. This rendered auditory feedback unreliable and thus resulted in an increased weighting of their feedforward mechanism (Scheerer & Jones, 2014) and smaller compensatory responses. In contrast, when participants received deviant auditory feedback that was not predictable in magnitude, they responded with larger compensatory responses. This suggests that they were unable to recognize that the perturbations were from an external source, and they attempted to correct for the perturbations as if they were self-produced errors. Because participants in this condition were introduced to unpredictable auditory feedback, Scheerer and Jones (2014) suggested that participants paid more attention to their auditory feedback in order to correct online for vocal errors, and thus weighted their feedback mechanism more heavily. Thus, although the feedback and feedforward mechanisms work together to create fluent speech, their differential weighting leads to responses that differ under varying conditions (Liu et al., 2015; Scheerer et al., 2013; Scheerer & Jones, 2014).

Adaptation

In addition to using the PP, researchers test the importance of auditory feedback for speech motor control and observe the differential weighting of feedback and feedforward mechanisms with the AP, which is suggested to be geared toward the observation of sensorimotor learning (Houde & Jordan, 1998; Keough, Hawco & Jones, 2013). During the adaptation paradigm, the participant is exposed to persistent, deviant auditory feedback for the entire vocalization. This paradigm has been used in some studies to alter F0, and in other studies to alter formant frequencies. When participants are exposed to deviant auditory feedback, sensorimotor learning is observed in the compensatory responses produced as they attempt to restore their perceived F0 (pitch) or formant frequencies to baseline, or to its unaltered state (Guenther, 2006; Houde & Jordan, 1998; Scheerer & Jones, 2014). Based on these responses it has been suggested that when an error is perceived, the participant increases their reliance on auditory feedback in an attempt to remap their sensorimotor representations and correct for the deviant auditory feedback (Guenther, 2006; Guenther & Vladusich, 2012). Then, when auditory feedback is returned to normal in both F0 and formant frequency, because their sensorimotor representations have been updated, the participant generally continues to compensate despite the absence of deviant auditory feedback (Houde & Jordan, 1998; Keough, Hawco & Jones, 2013). This happens because the participant becomes accustomed to their consistently altered **v**oice and remaps and strengthens their sensorimotor representations. Despite the cessation of deviant auditory feedback, the participant still ‘expects’ to hear their altered voice, thus they continue to compensate even though the alteration is no longer in place. This effect, called an aftereffect, takes time to dissipate until the voice returns to normal in the absence of deviant auditory feedback (Hawco & Jones, 2009; Keough, Hawco & Jones, 2013; Jones & Keough, 2008; Scheerer & Jones, submitted). Aftereffects are important because they demonstrate the degree to which an individual has updated their sensorimotor representations as a result of exposure to FAF.

A number of recent studies have demonstrated that speakers respond to changes in auditory feedback in the FAF adaptation paradigm based on how they weight their feedback and feedforward systems. For example, Jones and Keough (2008) conducted a study with F0 to observe differences in the way that singers and non-singers process and respond to auditory feedback. Both singers and non-singers participated in an adaptation paradigm where they produced vocalizations and had their F0 shifted at utterance onset (Jones & Keough, 2008). Jones and Keough found that singers produced smaller compensatory responses to FAF in comparison to non-singers. But when auditory feedback was returned to normal, singers showed larger aftereffects than non-singers (Jones & Keough, 2008). On the other hand, non-singers produced larger compensatory responses to FAF, but when auditory feedback returned to normal, this population showed smaller aftereffects (Jones & Keough, 2008). This pattern of results was suggested to have occurred because singers more frequently encounter situations where they must rely very heavily on their sensorimotor representations (i.e. when singing in a choir where reliable auditory feedback is not available). For this reason, singers have more experience increasing the weighting on their feedforward input when reliable auditory feedback is not available.

As a result of this increased weighting of the feedforward input, it was suggested that singers were less susceptible to the deviant auditory feedback, thus they produced smaller compensatory responses relative to non-singers. Despite this reduced susceptibility to the deviant auditory feedback, singers were not completely unaffected by the deviant auditory feedback. Overtime, the singers did produce compensatory responses to the deviant auditory feedback, suggesting that they were using the deviant auditory feedback to remap their sensorimotor representations, but just not to the same extent as the non-singers. When the deviant auditory feedback was then removed, singers showed larger after-effects. Again, this is because singers weight the feedforward system more heavily, so when their auditory feedback was returned to normal, it took them longer to remap their sensorimotor representations to take into account the now unaltered auditory feedback. On the other hand, non-singers who rely more on feedback control were quick to revert back to their pre-manipulation F0, resulting in smaller after-effects.

Although the differences and some similarities of F0 and formant frequency speech studies have been highlighted, the methodology of formant frequency studies has not yet been emphasized. Formant frequency studies differ from F0 studies in methodology since F0 studies alter the pitch of the vocalization, whereas formant frequency studies alter the vowel in consonant-vowel-consonant (CVC) words, which generally makes the vocalized word have a different meaning. For example, in order to observe how altered formant frequencies of isolated vowels affects speech, Purcell and Munhall (2006) altered vocalizations with the vowel \e\ to sound like \ae\ or \i\. Purcell and Munhall (2006) found that participants compensated for the imposed formant frequency alteration, and suggested that auditory feedback control for F0 and formant frequencies was similar. In another study, Houde and Jordan (2002) observed sensorimotor learning in participants when whispered vocalizations were altered. The formant frequency of CVC words was altered from an \e\ vowel to either an \a\ or an \i\ vowel and the altered auditory feedback was presented back to participants in real time

(Houde & Jordan, 2002). Houde and Jordan (2002) concluded that participants compensated in response to the altered auditory feedback and also retained these responses. Thus, aftereffects similar to those observed for F0 adaptation paradigms were detected.

Although formant frequency speech studies are invaluable in speech research and examine online corrective behaviour (Guenther, 2006; Guenther & Vladusich, 2012), F0 speech studies allow for the measurement of online error correction in addition to the study of sensorimotor adaptation, which is a primary reason why F0 is used in the current research. For example, Keough, Hawco and Jones (2013) conducted a study to observe if instructions to compensate for or ignore deviant auditory feedback regarding F0 influenced their compensatory responses and sensorimotor adaptation. They found that regardless of musical experience, no participants could control their compensatory responses or sensorimotor learning when the deviant auditory feedback occurred at vocalization onset. Despite this, individuals with vocal experience (singers) had previously been shown to reduce their compensatory responses when deviant auditory feedback occurred after vocalization onset (Keough, Hawco & Jones, 2013). Median 1500 values were averaged across trials, calculated as the median F0 of the first 1500 ms of each utterance produced by a participant (Keough et al., 2013). This measure has been suggested (Hawco & Jones, 2009) to index feedback control because F0 is calculated once auditory feedback is available to the participant after processing delays of approximately 100 ms (Burnett et al., 1997). Because auditory feedback is available to the participant, they use information from the feedback to monitor and correct their vocalizations. Since previous literature has shown that compensatory responses generally occur 100-150 ms after the onset of the perturbation (Burnett, Senner & Larson, 1997), and median 1500 values are calculated 1500 ms after the onset of the vocalization, this measure allows for the observation of feedback driven responses. Although median 1500 values were used in Keough, Hawco and Jones' (2013) study, it has also been used in many other empirical papers that concern F0 (Scheerer, Jacobson & Jones, 2016; Scheerer & Jones, submitted).

As mentioned, in addition to allowing the evaluation of feedback driven responses, APs that explore the control of F0 allow the study of sensorimotor adaptation. For example, Hawco and Jones (2009) observed responses to deviant F0 auditory feedback at mid-utterance and at utterance onset and found that responses differed. In order to analyze the data, Hawco and Jones (2009) calculated the median F0 of the first 50 ms of each vocalization (other studies have used the first 80 ms of the vocalization; Scheerer & Jones, submitted). Since auditory feedback is unavailable during the first 100 ms after vocalization onset, this measure is assumed to index feedforward control. Hawco and Jones (2009) found that responses to mid utterance shifts were smaller than responses to full utterance shifts. Their results suggest that different speech motor control strategies are used for different situational demands, in this case for mid utterance shifts versus utterance onset shifts. With mid utterance shifts, a stabilization mechanism is elicited since altered auditory feedback is compared to the previous unaltered F0 of the vocalization and auditory feedback is weighted more heavily. Differently, with deviant auditory feedback at utterance onset, current auditory feedback is compared to internal sensorimotor representations since there is no normal F0 to compare to, and thus the feedforward system is more heavily weighted (Hawco & Jones, 2009).

Across-Speaker Variability

In addition to the size of the compensatory responses to FAF and response latencies, researchers have also investigated the variability of participants' vocal productions. Vocal variability is usually calculated as the standard deviation of a baseline (unaltered) period of the vocalization, which is prior to the onset of the perturbation in the case of a PP (Scheerer & Jones, 2012), or prior to exposure to FAF in an AP (Scheerer & Jones, submitted).

Recently, Scheerer and Jones (2012) exposed participants to FAF perturbations and found a relationship between vocal variability (the standard deviation of the F0 during the period 100 ms before the pitch shift) and compensatory responses. This suggested that better vocal motor control, or a less variable voice, makes individuals less susceptible to the FAF manipulation and leads to smaller compensatory responses (Scheerer & Jones, 2012). In a follow up study, Scheerer and Jones (submitted) investigated the relationship between vocal variability and responses observed during an AP. They found that participants who were more variable produced larger compensatory responses (median 1500 values) and smaller aftereffects (median 80 ms values), while individuals who were less variable produced smaller compensatory responses but larger aftereffects (Scheerer & Jones, submitted). This led the authors to suggest that individuals with more variable F0 productions, or who deviated more from their average habitual F0, compensated more because they weighted their feedback system more heavily (Scheerer & Jones, submitted). Since the feedback system was more heavily weighted than the feedforward system, errors in auditory feedback were more readily incorporated into their ongoing vocalizations, which is why larger compensatory responses were observed (Scheerer & Jones, submitted). Smaller aftereffects were observed because normal F0 auditory feedback was incorporated into ongoing vocalizations quickly. Scheerer and Jones' results also led to the suggestion that individuals who are less variable weight the feedforward mechanism more heavily. Since the feedforward system is more heavily weighted than the feedback system for those individuals, errors in auditory feedback were less salient; thus, smaller compensatory responses were observed for this population (Scheerer & Jones, submitted). On the other hand, larger aftereffects were produced by the less variable individuals. This was suggested to occur because, for those individuals, the feedforward system was more heavily weighted and consequently, normal F0 auditory feedback took longer to be incorporated into ongoing vocalizations once deviant auditory feedback was no longer presented (Scheerer & Jones, submitted). Since individuals who were more variable showed different responses to FAF than individuals who were less variable, the results suggest that individuals who are more variable did not use the deviant auditory feedback in the same way to update their sensorimotor representations to the same extent as individuals who were less variable.

Scheerer and Jones' (2012, submitted) finding that individuals who are more variable weight feedback more heavily are comparable to Jones and Keough's (2008) finding. Jones and Keough (2008) found that individuals with less vocal practice (non-singers) weight feedback more heavily, in comparison to individuals with more vocal practice (singers). Combined, the results of these studies suggest that individuals with less vocal practice weight their *feedback* mechanism more heavily and are theoretically more variable. Conversely, individuals with more vocal practice weight their *feedforward* mechanism more heavily and are theoretically less variable. Generally, having less practice using feedback to regulate speech means that sensorimotor representations are not remapped (Burnett, McCurdy & Bright, 2008; Jones & Keough, 2008; Scheerer & Jones, submitted). Because individuals with less vocal practice pay more attention to their auditory feedback they are able to incorporate it more readily into their ongoing vocalizations, which is why they produce smaller aftereffects (Guenther, 2006; Jones & Keough, 2008). On the other hand, individuals with more vocal practice are able to remap sensorimotor representations and are less susceptible to errors (Jones & Keough, 2008). Because of increased feedforward control, it also takes these individuals longer to unlearn remapped associations between motor commands and their sensory consequences (Jones & Keough, 2008). Thus, these individuals take longer to de-adapt (Jones & Keough, 2008, Scheerer & Jones, 2012, 2014; Villacorta, Perkell & Guenther, 2007).

Individual Differences

It is evident from previous literature that situational demands (Hawco & Jones, 2009; Scheerer & Jones, 2014) and experience (Keough, Hawco & Jones, 2013; Jones & Keough, 2008; Scheerer & Jones, 2014, submitted) cause the feedback and feedforward systems to be weighted differently. Given the large individual differences observed in the responses measured in both the perturbation and adaptation paradigms, it is important to isolate which factors cause speakers to respond differently. Understanding these individual differences will inform models of speech motor control.

One factor that can lead to differences in how the feedback and feedforward mechanisms are weighted is age. Scheerer, Liu and Jones (2013) used the PP to observe the importance of auditory feedback for vocal production across development until early adulthood. Based on observations of compensatory responses of individuals aged 4 to 30 years old, it was found that vocal variability decreased with age until early adulthood. That variability decreases with age highlights the importance of long-term exposure to auditory feedback and the complete development of the vocal tract for the regulation of the vocal articulators. From this result, it is clear that individuals come to rely more on their feedforward mechanism, not only with practice with the production of speech with a fully developed vocal tract, but also with age, until at least early adulthood. This is one explanation of why vocal variability decreases with age and development until early adulthood, because with practice, individuals weight their feedback mechanism less. Furthermore, this literature highlights how age is one factor that can help to understand why different individuals weight their feedback and feedforward mechanisms differently, and can shed light onto how the speech motor control system is regulated based on different circumstances.

Another variable that can lead to dissimilarities in how the feedback and feedforward mechanisms are differentially weighted is experience. As previously mentioned, Jones and Keough (2008) evaluated the differences in the way that singers and non-singers process and respond to auditory feedback, using an AP. Their results suggested that non-singers did not remap their sensorimotor representations as readily as singers and relied more heavily on their feedback mechanism. The results of this study suggest that vocal experience affects how individuals weight their feedback and feedforward systems. Better empirical information about how vocal experience can account for different responses observed across subjects in response to FAF will advance our understanding of the speech motor control system.

Another study conducted by Giuliano et al. (2011) illuminates how an individual difference, such as an individual's first language, contributes to the variation in participants' responses to F0 discrimination tasks. English speakers use F0 for postural control in speech (Jones & Munhall, 2002) while individuals who speak tonal languages use F0 for information about lexical meaning (Deutsch, Henthorn & Dolson, 2004; Jones & Munhall, 2002). Giuliano et al., (2011) observed the production and perception of pitch in both English and Mandarin native speakers. Mandarin speakers were found to be more accurate in the detection of changes in pitch (Giuliano et al., 2011). This suggests that individuals who speak Mandarin, a tonal language, are more sensitive to small changes in pitch in comparison to English speakers (Giuliano et al., 2011). Furthermore, the study highlights that language experience changes individual responses to pitch manipulations. Knowledge of how different experiences, like language, affect responses to speech manipulations can give more insight into how the speech motor control system functions across many different experiences and situations.

Other studies have shown that attentional load can affect individual responses to the FAF manipulation, although there has not been a consensus in the results. Tumber, Scheerer & Jones (2014) observed how attentional load affected responses to altered auditory feedback through the introduction of perturbations to the participants' vocalizations when they were either in a divided attention task, such as identification of visual stimuli, or in the control condition. They found that when attention was divided between the vocalization task and a distractor task, participants produced smaller compensatory responses to FAF. This suggests that when attention is divided, individuals use auditory feedback differently than when attention is focused on a singular task (Tumber, Scheerer & Jones, 2014). Another study conducted by Liu et al. (2015) observed the role of selective attention towards one's own speech and compensatory responses. They found that when participants selectively attended to their auditory feedback, their compensatory responses were larger (Liu et al., 2015). This makes sense since individuals who weight their auditory feedback more heavily are known to produce larger compensatory responses (Scheerer & Jones, 2012). Alsius, Mitsuya and Munhall (2013) also observed how attentional resources are used in response to altered auditory feedback. Participants performed a task at the same time as they produced a vocalization, which was perturbed. Alsius, Mitsuya and Munhall (2013) found that there was no difference in response to altered auditory feedback when attention was diverted to an arbitrary task compared to when there was no diversion in attention. This may suggest that attention plays a role in the processing of F0 feedback, but not in the processing of formant frequencies. Because of this, attentional load is important when considering individual differences in response to FAF. How responses vary, subject to subject, reflects the speech motor control system as a whole.

The individual differences observed in attention may also affect factors other than responses to FAF. In order to observe inhibitory motor control of individuals with diminished attentional capacities, Dimoska et al., (2003) conducted a study and observed children with attention deficit disorder (ADD). Participants took part in a stop signal paradigm where a visual task required participants to make a two choice discrimination. They were then required to inhibit their response to the two choice discrimination task when indicated by an auditory tone (Dimoska et al., 2003). Dimoska et al., (2003) found that individuals with ADD exhibited deficits in the inhibition of responses to the task. This indicated that they are slower to process inhibition and the auditory stimuli. These results suggest that attentional deficits change how individuals respond when motor control is involved (Dimoska et al., 2003). When it comes to how attention modulates responses to inhibitory motor control, the individual differences observed in this study allow for a better understanding of how different factors can account for responses that vary to motor control paradigms. Furthermore, this shows how individual differences in attention is an important construct that contributes to many factors such as responses to FAF stimuli and inhibitory motor control.

There are also other effects in addition to attention that have been shown to modulate responses to FAF. For example, Donath, Natke and Kalveram (2002) conducted a study to observe how responses to FAF stimuli highlighted different features of speech in regards to F0. They altered the auditory feedback from the first two syllables of nonsense words produced by participants (Donath et al., 2002). They found that instead of altered auditory feedback only affecting the syllable in which it was presented, the effects extended over the entire vocalization (Donath et al., 2002). Thus, Donath et al. (2002) concluded that F0 control of speech does not simply aid in regulation of speech, it also plays a role in how the prosody of speech is encoded. The context of prosody discovered in this study is another factor that helps to account for differences in responses to FAF stimuli. This further reflects how individual differences aid in the development of a better comprehension of the speech motor system. This is important since the information that prosody provides during the production of speech aids in how syntax and semantics are processed, which are all important aspects of speech that must be understood in order to comprehend the speech motor system (Cutler et al., 1997; Donath, Natke & Kalveram, 2002).

The Current Study

It is clear that individual differences exist in response to the FAF manipulation when factors such as age, experience through vocal training, experience through native language, situational demands, variability and attentional load are considered. Individual responses to the FAF manipulation of each of these factors have been shown to differ subject to subject. However, it is important to account for these differences to observe how these factors dictate the weighting of the feedback and feedforward systems. By understanding how the inputs are weighted, we can gain insight into how the speech motor system functions (Purcell & Munhall, 2006). From this, new models can be developed to describe how the feedback and feedforward mechanisms are differentially weighted.

Although both the PP and AP evaluate how deviant auditory feedback influences speech motor control, the PP allows for the observation of responses that are reflexive during ongoing speech, while the AP allows for the investigation of the use of auditory feedback for speech motor planning. Previous research has shown that individuals who are more variable produce larger compensatory responses to feedback perturbations (Scheerer & Jones, 2012), and during sensorimotor adaptation experiments (Scheerer & Jones, submitted). Although we assume that the feedback mechanism driving responses to quick perturbations in the PP is the same mechanism responsible for the response to whole utterance shifts in the AP (as measured by the median F0 value of the utterance), no study has directly tested the relationship between these responses. In the present study therefore, we exposed the same subjects to the FAF perturbation and FAF adaptation procedures. Based on the assumption that the feedback responses were driven by the same brain processes, we expected that compensatory responses produced in the PP would be positively correlated with compensatory responses produced in the AP.

However, if compensatory responses are not positively correlated across the PP and AP, it may suggest that auditory feedback is used differently for brief perturbations than for whole utterance F0 shifts. For example, some researchers have claimed that the PP elicits the PSR, which is a mechanism that tries to stabilize the voice (Bauer & Larson, 2003), while the AP causes speakers to compare their vocalization (which is altered at utterance onset) to previously mapped sensorimotor representations (Hawco & Jones, 2009). Thus, if positive correlations are not found it is possible that auditory feedback is used differently across the paradigms.

Finally, as previously mentioned, individuals who are more variable have been shown to rely more on auditory feedback and compensate more in response to FAF, compared to individuals who are less variable, who are believed to rely more on their sensorimotor representations (Scheerer & Jones, 2012). In addition, research in our lab has shown that vocally untrained speakers rely more on auditory feedback, and compensate more than vocally trained speakers, who rely more on their sensorimotor representations (Jones & Keough, 2008). At the same time, vocally untrained speakers produced smaller aftereffects in comparison to untrained speakers (Jones & Keough, 2008). Based on these results, we expected to observe a negative correlation between compensatory response size and aftereffect size in the AP.

Methods

Participants

There were 130 participants between the ages of 17 and 27 years (M = 19.54, SD = 2.74; 91 females, 35 males, 4 unidentified gender) that took part in this research study. Participants were recruited through the PREP (Psychology Research Experience Program) system at Wilfrid Laurier University. Participants were compensated with credit toward their respective Psychology classes. One participant who spoke a tonal language was not included in the study. All other participants did not speak a tonal language and had no formal vocal experience. All participants were required to complete a consent form, as well as a language questionnaire (refer to Appendix A). This research was approved by the Wilfrid Laurier University Research Ethics Board.

Apparatus

Participants were seated in front of a Samsung desktop monitor in a small room at Wilfrid Laurier University. The participants wore Sennheisser headphones (Sennheisser HD 280-13 Pro, Sennheiser Electronics, Germany) and a headset microphone (Apex 575 Universal Low- Profile Condenser Microphone). Vocalizations were sent to a Presonus Firestudio digital mixer (Presonus, Baton Rouge, LA) controlled by a Mac Mini (Apple, Cupertino, CA) where they were mixed with the use of Studio One Software (Presonus, Baton Rouge, LA) and then sent to a VoiceOne shifter/ digital signal processor (DSP; VoiceOne, T.C. Helicon, Victoria, BC). This shifted the participants' auditory feedback down 100 cents as part of a FAF paradigm. The participants heard their shifted voice fed back to them in real time as auditory feedback during each vocalization. Visual stimuli and the onset of the FAF during the perturbation paradigm were controlled through the use of MAX5 MSP (Cycling '74, San Francisco, CA). The visual stimuli during the AP were controlled through the use of Microsoft Powerpoint. The unaltered voice signal was recorded at a sampling rate of 44.1 kHz for later analysis.

Experimental Procedure

Participants were asked to complete consent forms and pre-test measures (refer to Appendix A), and were then instructed to put on headphones and a headset microphone. Participants were told that they would participate in a vocalization experiment and were instructed to vocalize an /a/ sound. They were specifically told to keep their vocalization consistently an /a/ sound and were corrected during the study if they deviated from this sound. Participants were instructed to select any pitch they were comfortable with and to try to keep it as consistent as they could. Participants were told that their voice may sound “funny” but to continue with their vocalization at a consistent pitch. Finally, participants were told that there would be a red and green square that alternate on the computer screen in front of them, and that they were to vocalize for the entire time the square was green and to stop their vocalization when the square turned red. There were two phases to this experiment: perturbation and adaptation. In between phases, participants were offered a short break. The perturbation and adaptation phases of this study were counterbalanced. Participants were debriefed upon the conclusion of the study.

Experimental Procedure: Perturbation Paradigm + Perturbation Data Analysis

In the perturbation phase, the participants produced 60 vocalizations in total, split up into two blocks of 30 vocalizations, with an opportunity to take a break between the blocks. There were 25 trials in each block in which participants’ auditory feedback was altered, and 5 trials where it was left unaltered. Each altered vocalization was perturbed downwards 100 cents (one semitone) 4 times for 200 ms during each perturbation. Each vocalization lasted approximately 4.5 seconds. Altered and unaltered trials were presented pseudo-randomly.

In this paradigm, compensation responses were measured in response to the perturbed auditory feedback. The recorded vocalizations were segmented into individual utterances and converted from Hertz to cents through the use of the formula $Cents=100(12Log_2(F/B))$ where F= F0 value in Hertz and B= mean frequency of the baseline period. Cents values were calculated for the baseline period (100 ms before the F0 perturbation), as well as the 500 ms after the F0 perturbation. Variability was calculated as the standard deviation of the F0 in cents within the baseline period. The magnitude of the compensatory response was calculated as the maximum deviation of the average F0 (the peak maximum) from the baseline period average. The latency of the onset of the vocal response was calculated as the time between perturbation onset and the time the participants' F0 deviated two standard deviations from the average F0 of the 100 ms baseline period. The latency of the peak magnitude of the response was calculated as the time between the perturbation onset and the time at which the participants reached the maximum F0 value.

Experimental Procedure: Adaptation Paradigm + Adaptation Data Analysis

Instructions to the participant for this phase of the study were similar to the perturbation phase, with the exception that this phase did not offer a break. In this phase of the study participants produced 100 vocalizations consecutively. The first ten (trials 1-10) and the last ten (trials 91-100) vocalizations were unaltered, while the middle 80 (trials 11-90) vocalizations were altered by decreasing participants F0 by 100 cents for the entire utterance. Vocalizations were 3.5 seconds in duration.

In this paradigm, compensation responses to consistently altered auditory feedback were measured in addition to aftereffects. Vocalizations were segmented into individual utterances and converted from Hz to cents using the formula $Cents=1200(Log_2(F/B))$ where F= F0 value in Hz and B= habitual F0 value (calculated by averaging M1500 of the baseline phase). Median 80 values were calculated as the median F0 of the first 80 ms for each vocalization and median 1500 values were calculated as the median F0 for the first 1500 ms for each vocalization.

Median 80 values deliver information about the F0 at initiation of the vocalization. At the first 80 ms of each vocalization, auditory feedback information is not available due to neural processing delays (Burnett et al., 1997; Hawco & Jones, 2009). Thus, median 80 captures the F0 of the participants' vocalization at the initiation of a vocalization, before auditory feedback is available. Because median 80 values are measured at utterance onset before auditory feedback is available, it provides information about sensorimotor learning and further indexes the feedforward system.

Median 1500 values are also important since they measure the F0 when auditory feedback information from the vocalization is available. Due to the fact that median 1500 values measure a larger portion of the vocalization, it passes the time frame of processing delays (Hawco et al, 2009; Keough, Hawco & Jones, 2013; Keough & Jones, 2011). Since this value measures how much altered auditory feedback was used to stabilize ongoing vocalizations, median 1500 values are an indication of the use of the feedback system (Hawco et al, 2009; Keough, Hawco & Jones, 2013; Keough & Jones, 2011).

Vocal variability measures how much the participant deviates from their habitual F0 (Scheerer & Jones, submitted). The standard deviation of the first 1500 milliseconds (ms) of each vocalization also provides an indication of F0 variability of a participant's vocalization. This was calculated by taking the average standard deviation of the first 1500 ms of trials 1-10, the first ten unaltered vocalizations.

Statistical Analysis

For statistical analysis, vocalizations in the AP were separated into four groups including baseline (trials 1-10), shift start (trials 11-20), shift end (trials 81-90) and test phase (trials 91-100). Compensatory responses were calculated by subtracting the average of the last ten vocalizations of the shifted trials (the shift end trials) from the first ten vocalizations (the baseline trials) for both median 80 and median 1500 values. Aftereffects were calculated by subtracting the average of the last ten vocalizations (the test phase) from the first ten vocalizations (the baseline trials) for both median 80 and median 1500. Aftereffects measure if compensation responses continue after auditory feedback is no longer altered. Two variability measures that reflected early and later portions of the vocalization were also calculated. Specifically, standard deviation of the median 80 (early) and median 1500 values across the baseline (trials 1-10; Scheerer and Jones, 2014) were calculated. To ensure that variability was accurately reflected for the production of the entire utterance (median 1500), and to attempt to mirror how it is usually calculated in the PP, variability was recalculated by taking the average standard deviation of random samples every 100 ms from the first ten unaltered trials. The results did not change when variability was recalculated, therefore results are reported with the original variability calculation. In some instances, the degrees of freedom do not reflect the sample size of 130 participants. This is because in some cases, there were errors in tracking vocal pitch. Thus, the data for those specific cases the measure for that participant was not used in the statistical analysis.

Two separate repeated measures analysis of variances (RM-ANOVAs) were conducted in order to observe how median 80 and median 1500 values changed over the different trial phases (including baseline, shift start, shift end and test phase). For each RM-ANOVA, post hoc least significant difference (Bonferroni) tests were run to examine the differences between each phase. Although original degrees of freedom are reported for ease of interpretation, the Greenhouse-Geisser correction was used in instances where Mauchley's assumption of Sphericity was violated (Greenhouse and Geisser, 1959). Slope of the adaptation response over trials was calculated to observe learning through the use of the formula $b= \in (x-\bar{x})(y-\bar{y}) / \in (x-\bar{x})^2$ for the first 80 ms of the data as well as the first 1500 ms of the data.

Within the PP, t-tests were run to observe if shifted trials were different from unshifted trials. Shifted trials were trials that provided the participant with deviant auditory feedback, whereas unshifted trials provided the participant with auditory feedback that was not altered. The baseline value (the unshifted portion of the vocalization 100 ms prior to the shift) as well as standard deviation for each vocalization was also calculated to observe variability within the vocalization of each participant. Values (in cents) were calculated before (baseline condition) and after the F0 shift. The standard deviation of the baseline condition was calculated as a measure of vocal variability for each individual. Compensation maximum was also calculated through the observation of peak deviation from the baseline.

To investigate the relationship between responses across the two paradigms, Pearson's correlations were conducted. The correlation between compensatory responses in the PP and the AP was calculated, while the correlation between compensatory responses in the PP and after-effects in the AP were also calculated. Pearson's correlations were also conducted to assess the relationship between compensatory responses and aftereffects within the adaptation paradigm.

Results

Adaptation

To determine if the experimental paradigm was successful at producing adaptive responses, RM-ANOVAs were conducted to examine mean differences across the experimental phases. The phases consisted of baseline (trials 1-10; unaltered trials), shift start (trials 11-20; altered trials), shift end (trials 81-90; altered trials) and test (trials 91-100; unaltered trials).

M80

A RM-ANOVA was conducted to investigate the differences across the trial phases (including baseline, shift start, shift end and test phase) on median 80 values. This showed a main effect of trial phase, $F(3, 360) = 24.24$, $p < .001$ (see Figure 3). Pairwise comparisons showed that median 80 values for the baseline phase (trials 1-10) were significantly smaller than the shift start phase (trials 11-20; $p<.001$), shift end phase (trials 81-90; $p<.001$), and test phase (trials 91-100; $p<.001$). Pairwise comparisons also showed that the median 80 values for the shift start phase (trials 11-20) were significantly smaller than the shift end phase (trials 81-90; p=.001). The final significant pairwise comparison showed that median 80 values for the shift end phase (trials 81-90) were significantly larger than the test phase (trials 91-100; p=.024).

Pearson's correlational analyses were used to observe the relationship between vocal variability (using median 80 values) and compensation (calculated using median 1500 values) in the AP. This relationship, $r(118) = .063$, $p= .496$, was not significant. Additionally, the relationship between vocal variability (using median 80 values) and aftereffects (using median 80 values) in the AP, $r(118) = .111$, $p= .227$, was also not significant.

M1500

A RM-ANOVA was conducted to investigate the differences across the trial phases (including baseline, shift start, shift end and test phase) for the median 1500 values. This showed a main effect of trial phase, $F(3, 360) = 27.71$, $p< .001$ (see Figure 4). Pairwise comparisons showed that median 1500 values for the baseline phase were significantly smaller than the shift start phase (p<.001), shift end phase (p<.001), and test phase (p<.001). Pairwise comparisons also showed that median 1500 values for the shift start phase (trials 11-20) were significantly smaller than the shift end phase (trials 81-90; p=.016). The final significant pairwise comparison showed that median 1500 values for the shift end phase (trials 81-90) were significantly larger than the test phase (trials 91-100; p<.001).

Pearson's correlational analyses were used to observe the relationship between vocal variability (using median 1500 values) and compensation (using median 1500 values) in the AP. This relationship, $r(118) = .066$, $p = .473$, was not significant. Differently, the relationship between vocal variability (using median 1500 values) and aftereffects (using median 80 values) in the AP, $r(118) = .245$, $p = .007$, was significant (See Figure 5).

Another Pearson's correlation was conducted using measures from the AP including compensatory responses (using median 80 and median 1500 values) and aftereffects (using median 80 values) to observe if compensation in the AP was related to sensorimotor learning. The correlation between compensatory responses (using median 80 values) and aftereffects (using median 80 values), $r(119) = .130$, $p = .157$, was not significant. Differently, the correlation between compensatory responses (using median 1500 values) and aftereffects (using median 80 values), $r(119) = .705$, $p < .001$ (see Figure 8), was significant.

Learning

To observe the relationship between the rate of learning and aftereffects in the adaptation paradigm, the slope of median 80 and median 1500 values were investigated. The relationship between aftereffects (using median 80 values) and the slope of median 80 values from the altered trials (trials 11-90) , $r(118) = .152$, $p = .098$, was not significant. Conversely, the relationship between aftereffects (using median 80 values) and the slope of median 80 values from the last ten unaltered trials (trials 91-100; test phase), r(118)= -.204, p= .025, was significant. This significant relationship means that as aftereffects increased, so did sensorimotor learning. The relationship between aftereffects (using median 80 values) and the slope of median 1500 values from the altered trials (trials 11-15 indexed by feedback control), $r(118) = .420$, $p < .001$, was also significant.

Pearson's correlational analyses were also used to observe the relationship between median 1500 values during the shift end phase (trials 81-90) and the slope of the test phase (trials 91-100). This relationship between compensatory responses in the adaptation paradigm and the rate at which the median 1500 F0 values returned to baseline values, $r(118) = -.167$, $p = .068$, was marginally significant. Thus, larger compensations during the shifted trials were related to quicker de-adaption. However, the relationship between median 1500 values during the shift end phase and the median 80 values during the shift end phase, $r(118) = -.116$, $p = .206$, was not significant. On the other hand, the relationship between the median 1500 values during the shift end phase and the slope of median 1500 values from the altered trials during the start of the shift phase (trials 11-15), r(118)= .549, p<.001, was significant. Thus, speakers who learned to compensate faster achieved larger magnitude compensations by the final shifted trial.

Perturbation

Compensation & Variability

A paired samples t-test was conducted to determine whether compensatory responses (in the PP) were different across the altered and unaltered trials to ensure that the FAF manipulation was successful. Response magnitudes differed across altered and unaltered trials such that the altered trials (M = 12.16 cents) were significantly higher than the unaltered trials (M = 4.45; $t(121) = -8.79$, $p < .001$).

A paired samples t-test was also conducted to determine whether vocal variability (standard deviation of the baseline period) differed across the altered and unaltered trials. Vocal variability was not found to differ across altered (M = .78 cents) and unaltered trials (M = .79), $t(121) = -.216$, $p = .830$.

Pearson's correlational analyses were conducted to determine whether there was a relationship between compensatory responses to F0 perturbations and vocal variability. The correlation between compensatory responses and variability was significant, $r(120) = .221$, $p = .015$ (see Figure 6).

Latency

Pearson's correlational analyses were used to observe the relationship between response latency measures and compensation in the PP. The correlation between response latencies for the maximum compensation magnitude (peak response latency) and the magnitude of compensatory responses, $r(120) = .305$, $p = .001$, was significant. Thus larger magnitude responses were positively related to longer latencies. Conversely, the correlation between the onset of vocal response latencies for the altered auditory feedback and the magnitude of compensatory responses, $r(120) = -.090$, $p = .367$, was not significant.

Perturbation and Adaptation Paradigms

Pearson's correlational analyses were used to assess the relationships between variables measured as part of the PP and variables measured as part of the AP.

The compensatory responses (in the PP) were compared with the median 1500 values (related to compensation) and median 80 values (related to adaptation) in the AP. The correlation between compensatory responses in the PP and compensatory responses (using median 1500 values) in the AP was not significant, $r(113) = -.011$, $p = .903$ (see Figure 7). However, the relationship between compensatory responses in the PP and adaptation responses in the AP (using median 80 values), $r(120) = .187$, $p = .039$, was significant.

The relationship between variability in the PP and the median 1500 and the median 80 values in the AP was investigated to determine if vocal variability in the PP was associated with great compensation and learning in the AP. Pearson's correlational analyses revealed that the relationship between variability in the PP and median 1500 values in the AP, $r(113) = .022$, $p = .815$, was not significant. Additionally, the relationship between variability in the PP and the median 80 values in the AP, $r(120) = -.036$, $p = .696$, was not significant.

The relationship between variability in the PP and aftereffects in the AP was investigated. Pearson's correlational analyses revealed that the relationship between variability in the PP and aftereffects as reflected by the median 80 values, $r(118) = -.042$, $p = .659$, was not significant. Additionally, the relationship between variability in the PP and aftereffects as reflected by the median 1500 values, $r(120) = -.063$, $p = .491$, was also not significant.

The relationship between variability in the PP and variability in the AP was also investigated to observe parity across the paradigms. The relationship between variability in the PP and variability (using median 80 values) in the AP, $r(113) = .002$, $p = .982$, was not significant. Additionally, the relationship between variability in the PP and variability (using median 1500 values) in the AP, $r(113) = .007$, $p = .944$, was also not significant.

Latency

Pearson's correlational analyses were used to observe the relationship between response latency measures in the PP and measures in the AP. The correlation between response latency for the maximum compensation magnitude in the PP and median 1500 values in the shift end phase (trials 81-90) in the adaptation paradigm, $r(113) = -.044$, $p = .643$, was not significant. The relationship between response latency for the maximum compensation magnitude and median 80 values during the test phase (trials 91-100), $r(113) = -.097$, $p = .302$, also was non-significant. Additionally, the correlation between the latency of the vocal response onsets in the PP and median 1500 values in the shift end phase (trials 81-90) in the AP, $r(96) = -.032$, $p = .758$, was not significant. As well, the relationship between vocal response onset latencies in the PP and median 80 values during the test trials (aftereffects), $r(96) = -.042$, $p = .684$, was also non-significant.

Pearson's correlational analyses were used to observe the relationship between response latency measures in the PP and variability in the AP during the baseline phase (trials 1-10). The correlation between response latency for the maximum compensation magnitude in the PP and variability of the median 80 values, $r(113) = .067$, $p = .475$, was not significant. The relationship between peak response latencies in the PP and variability of the median 1500 values, $r(113) = .060$, $p = .524$, was also non-significant. Additionally, the correlation between vocal response onset latencies in the PP and variability of median 80 values, $r(96) = -.067$, $p = .510$, was not significant. The relationship between vocal response onset latencies in the PP and variability of the median 1500 values, $r(96) = -.176$, $p = .083$, was also non-significant.

Finally, Pearson's correlational analyses were used to observe the relationship between response latency measures in the PP and rates of learning in the AP. The correlation between vocal response onset latencies in the PP and the rate of learning (de-adaptation) in the test phase (trials 91-100; using median 80 values; indexing feedforward speech control), $r(96) = .210$, $p < .05$, was significant. On the other hand, the correlation between vocal response onset latencies in the PP and the rate of de-adaptation as measured by the median 1500 values (indexing feedback control), $r(96) = .102$, $p = .316$, was not significant.

Discussion

Overview

To examine if speakers use auditory feedback in a related manner for online error correction and speech motor planning, participants were exposed to FAF during the PP and AP. In the PP, participants produced vocalizations while exposed to brief changes to their auditory feedback. This paradigm allowed us to observe how individuals use their auditory feedback to correct for pitch errors online using feedback control (Burnett et al., 1997; Elman, 1981; Guenther, 2006). In this paradigm, participants received auditory feedback that did not match their outgoing sensorimotor commands and were thus forced to rely more heavily on their auditory feedback, relative to feedforward control, to stabilize their vocalizations (Larson, Burnett & Kiran, 2000; Liu et al., 2015; Scheerer & Jones, 2012).

Differently, in the AP, participants were exposed to full utterance shifts, which allowed for the assessment of sensorimotor learning (Houde & Jordan, 1998; Keough, Hawco & Jones, 2013; Jones & Keough, 2008; Scheerer & Jones, submitted). Feedforward control was indexed through the observation of the first 80 ms of each participant's vocalization, as cortical processing delays auditory feedback for ~100 ms (Burnett et al., 1997; Hawco & Jones, 2009). This measure also allowed us to monitor sensorimotor learning, as participants used the altered auditory feedback to update their sensorimotor representations (Guenther, 2006; Guenther & Vladusich, 2012; Jones & Keough, 2008; Scheerer & Jones, submitted).

Vocal responses during these two paradigms were compared to better understand how the speech motor control system as a whole operates, and to shed some light on the differential weighting of feedback and feedforward inputs. Based on previous results, it was predicted that there would be a positive correlation between compensatory responses produced both during the PP and the AP, and a negative correlation between compensatory responses and aftereffects in the AP.

There was a significant main effect of trial phase on F0 values from the first 80 ms of the vocalization in the AP. This means that participants displayed sensorimotor adaptation as well as de-adaptation. There was also a main effect of trial phase on values from the first 1500 ms of the vocalization in the adaptation paradigm. This means that participants compensated to deviant auditory feedback in the AP. There was also a significant relationship between compensatory responses across shifted and non-shifted stimuli, which means that compensatory responses were elicited in response to the FAF manipulation in the PP. Additionally, there was a significant correlation between variability measured in the first 1500 ms of the vocalization and the median 80 F0 values during the test phase. This means that individuals who were more variable with their feedback control also produced larger aftereffects. Another significant correlation found was between compensatory responses (indexed by median 1500 values) in the AP and aftereffects. This means that the more a participant compensated in the AP, the larger aftereffects they displayed.

The correlation between the median 80 F0 values during the test phase and the slope of the first 1500 ms of the shifted vocalization was also significant. This means that the faster the participants' compensatory responses increased, the larger aftereffects they displayed when they heard their auditory feedback reverted back to their true F0. As well, there was a marginally significant negative relationship between compensation (median 1500) and the slope of the first 1500 ms of the vocalizations in the final trials of the test phase of the adaptation paradigm. This means that larger compensatory responses were negatively related to smaller aftereffects in the AP. There was also a correlation between compensation in the PP and compensation (measured by median 80 values) in the AP. This means that participants who compensated more in the PP were also better at learning to update their sensorimotor representations during shifted trials and began their vocalizations at a higher F0. Variability and compensatory responses also correlated in the PP. This means that the more variable a participant was, the more they compensated to the FAF manipulation. Lastly, there was a correlation between the timing of the onset of responses to the FAF manipulation in the perturbation paradigm and the slope of the first 80 ms of the vocalization during the test phase. This means that the faster a participant responded to the FAF manipulation in the perturbation paradigm, the larger the aftereffects they displayed when their auditory feedback was returned to their normal F0 in the adaptation paradigm.

M80 & M1500 Values

As often observed in APs (Hawco & Jones, 2009; Scheerer & Jones, submitted), median 80 values were smaller in the baseline phase compared to the shift start phase, the shift end phase, and the test phase. The fact that the shift start phase, shift end phase, and test phase were larger than the baseline phase shows that in response to downward FAF, participants changed the sensorimotor representations that guide F0 control to compensate for the FAF manipulation (see also Heinks-Maldonado et al., 2005; Houde & Jordan, 1998; Keough, Hawco & Jones, 2013). In addition, the test phase elicited smaller responses than the shift end phase. During the test phase, the auditory feedback presented back to the participant was no longer shifted, and thus the participant was able to use their normal auditory feedback to once again re-map their sensorimotor representations.

This process occurred gradually, as the participant re-adjusted their voice back to baseline based on unaltered auditory feedback (Houde & Jordan, 1998; Jones & Keough, 2008). This shows evidence of sensorimotor learning and that participants have to again remap their sensorimotor representations to account for the new unshifted auditory feedback (Burnett, McCurdy & Bright, 2008; Guenther, 2006; Scheerer & Jones, 2014). Together, the main effect of trial phase on median 80 values showed that participants displayed sensorimotor adaptation as well as de-adaptation.

Median 1500 values give a different kind of index in comparison to median 80 values. Median 1500 values index the use of auditory feedback during the ongoing vocalization and index the size of compensatory responses across vocal productions (Keough, Hawco & Jones, 2013; Scheerer & Jones, submitted). Median 1500 values in the baseline phase were significantly smaller than in the shift start, shift end, and test phase. Replicating previous research (Scheerer & Jones, submitted), the baseline phase was significantly smaller than the shift end phase. This shows that the altered auditory feedback presented to participants elicited compensatory responses. Responses were also significantly smaller in the shift start phase in comparison to the shift end phase. This shows that participants were compensating more at the end of their exposure to the FAF, relative to the beginning of their exposure to FAF. Additionally, responses in the test phase were significantly smaller than in the shift end phase. This reveals that when deviant auditory feedback was no longer available and normal F0 was presented to the participant, they were able to use the auditory feedback to compensate for the inaccurate vocal motor command produced by their sensorimotor representation because of the remapping that occurred during their recent exposure to the FAF. As a result, with the use of the auditory feedback they were able to slowly restore their vocalization to their pre-manipulation F0. In sum, the main effect of trial phase on median 1500 values showed that participants compensated when their F0 was shifted.

Compensatory Responses in the Perturbation Paradigm

The current research showed that F0 values in the perturbation paradigm were significantly different across the altered and unaltered trials. Thus, individuals' F0 increased in response to the FAF manipulation, replicating previous work (Bauer & Larson, 2000; Larson, Burnett & Kiran, 2000; Liu et al., 2015; Scheerer, Behich, Liu & Jones, 2013). This result is consistent across both F0 and formant frequency literature as compensatory responses to both speech characteristics occur in response to altered auditory feedback. No significant differences were observed between variability in altered and unaltered trials. This was expected since variability is measured during unaltered portions of the vocalization in order to index how much the vocalization deviates from the participant's habitual F0 (Scheerer & Jones, 2012).

Compensatory Responses in Perturbation vs. Adaptation Paradigms

To assess whether auditory feedback is used in a related manner for online error correction and speech motor planning, the relationship between compensatory responses in the PP and compensatory as well as adaptation responses in the AP was assessed. Main effects of the test phase were observed within the AP for both median 80 and median 1500 values. As well, compensatory responses were elicited in the PP. Despite this there was no correlation between compensatory responses in the PP and compensatory responses (using median 1500 values) in the AP.

There was a significant relationship found when adaptation responses in the AP (using median 80 values; indexing feedforward control) were compared to compensatory responses in the PP. Adaptation responses (using median 80 values) within the AP show how much individuals updated their sensorimotor representations and learned by the end of the shifted trials (trials 11-90) (Keough, Hawco & Jones, 2013; Scheerer & Jones, submitted). This relationship shows that participants who compensated more in the perturbation paradigm were also better at updating their sensorimotor representations during shifted trials and beginning their vocalizations at a higher F0.

The non-significant correlation between compensatory responses in the PP and compensatory responses (using median 1500 values) in the AP suggests not only that auditory feedback is differentially weighted across paradigms, but also that compensatory responses are not related across paradigms. The responses to each paradigm allow for the observation of different speech goals. The PP is used to investigate immediate error correction (Guenther, 2006; Larson, Burnett & Kiran, 2000; Perkell et al., 1997), whereas the AP is used to investigate speech motor planning, although both paradigms will invoke the use of feedback and feedforward inputs (Jones & Keough, 2008; Keough, Hawco & Jones, 2013; Scheerer & Jones, 2014). Previous literature has supported the conclusion that individuals respond differently to FAF when it is presented in different ways. For example, Hawco and Jones (2009) found that individuals responded differently to altered auditory feedback when it occurred at utterance onset compared to mid utterance onset.

From this, they suggested that different mechanisms are used to support diverse speech goals (Hawco & Jones, 2009). Support for this notion comes from a review by Perkell et al. (1997), who critically evaluated the F0 and formant frequency literature and concluded that the speech motor system uses auditory feedback for two main purposes; first, to maintain sensorimotor representations (feedforward control), and second, for the immediate correction of vocal errors (feedback control). These different speech goals are reasons the system may differentially weight feedback and feedforward input.

Although there may be different mechanisms supporting different speech goals, the results of the current research also suggest that because deviant auditory feedback is presented differently, compensatory responses do not relate across the PP and AP. Since there is no relationship between compensation in the PP and compensation (indexed by median 1500 values) in the AP, the errors induced in each paradigm must be treated differently. When vocal errors are made individuals use information derived from their auditory feedback to try to correct them, whether F0 or formant frequencies are manipulated (Guenther, 2006; Larson, Burnett & Kiran, 2000; Scheerer & Jones, 2012). Intermittent vocal errors persist throughout the PP. These intermittent vocal errors elicit a reflexive response meant to stabilize the ongoing vocalization through the comparison of the current altered segment of the vocalization to unaltered F0 (Hawco & Jones, 2009). The intermittent deviant auditory feedback persists throughout the paradigm, so the participant is not able to learn from the errors. Thus, participants are not able to update their sensorimotor representations, which explains why the feedback mechanism is weighted more heavily than the feedforward mechanism in this paradigm, although both inputs are used (Guenther, 2006; Scheerer & Jones 2014).

In contrast, the AP features a full utterance shift (Hawco & Jones, 2009). In this paradigm there is no sample of the normal, unshifted voice and only the presentation of whole utterance deviant auditory feedback during shifted trials (trials 11-90). Because the shift occurs at utterance onset, the participant must compare their current auditory feedback to their sensorimotor representation of the intended sound (Hawco & Jones, 2009; Jones & Keough, 2008; Scheerer & Jones, submitted). Due to this comparison, participants more heavily weight their feedforward mechanism over their feedback mechanism, although both are used. Deviant auditory feedback is still used to update sensorimotor representations so that the participant's feedback is no longer perceived as erroneous (Guenther, 2006; Hawco & Jones, 2009; Keough, Hawco & Jones, 2013; Keough & Jones, 2008; Scheerer & Jones, 2014, submitted). This occurs because the shift happens at utterance onset, so the participant does not have unaltered F0 to compare their current auditory feedback to (Hawco & Jones, 2009; Jones & Keough, 2008). Thus, error detection occurs differently across the FAF perturbation and FAF adaptation paradigms because of how deviant auditory feedback is presented.

Another reason for the lack of relationship between compensatory responses across paradigms is that compensation produced in response to a brief FAF perturbation might not necessarily be controlled in the same manner as compensation produced in response to a full utterance shift. Previous literature has displayed differences in responses to the FAF paradigms by observation of response size. Compensatory responses to the FAF manipulation in the perturbation paradigm have been known to often be a fraction of the size of the manipulation itself (Burnett et al., 1997; Burnett et al., 1998; Burnett & Larson, 2002; Chen et al., 2007). On the other hand, responses to the FAF manipulation in the adaptation paradigm are often larger (Hawco & Jones, 2009, 2010; Keough, Hawco & Jones, 2013; Keough & Jones, 2009, 2011). In the PP a reflexive response meant to stabilize the voice is elicited, therefore the goal of vocal stabilization prevents dramatic changes to vocal productions (Burnett et al., 1997, 1998; Burnet & Larson, 2003; Guenther, 2006; Scheerer & Jones, 2012, 2014). Participants in the PP rely heavily on feedback control. Because of this, if vocal stabilization did not occur, the participant would respond to errors based on only their auditory feedback, and thus have worse vocal motor control (Guenther, 206; Guenther & Vladusich, 2013). Thus, based on previous literature in combination with the present research, it is concluded that individuals do not respond the same when their auditory feedback is shifted after voice onset and when their auditory feedback is shifted at voice onset. Response sizes are different across paradigms since the compensatory response in the PP is meant to stabilize the voice and not necessarily meant to make corrections to the sensorimotor representation like the AP does (Guenther, 2006; Guenther & Vladusich, 2012; Hawco & Jones, 2009; Jones & Keough, 2008; Scheerer & Jones, 2014).

Previous literature has also shown support for the theory that there are different mechanisms used to respond to different types of speech errors. For example, Hain et al. (2000) investigated the PSR through the manipulation of instructions to participants. Two different responses to deviant auditory feedback were found: an early vocal response that tended to be more reflexive and a later vocal response that appeared to be more voluntary in nature (Hain et al., 2000). During early responses participants were unable to voluntarily control their response to FAF based on instructions to compensate for, or ignore, the deviant auditory feedback (Burnett et al., 1997; Hain et al, 2000; Hawco & Jones, 2009). Because of this, the early vocal response showed a higher reliance on sensorimotor representations at vocalization onset, similar to feedforward control (Hain et al., 2000). Differently, during later vocal responses participants were better able to control their response to FAF based on instructions to compensate for, or ignore, the deviant auditory feedback. Consequently, the later vocal response, similar to feedback control, displayed increased reliance on auditory feedback in order to control vocalizations (Hain et al., 2000). From this it is clear that the way auditory feedback is weighted is based on factors like instruction, and these previous results further support the current finding that compensatory responses are not related across paradigms.

Another study conducted by Scheerer and Jones (2014) observed how the predictability of deviant auditory feedback affects responses to the FAF manipulation. They observed that the presentation of predictable auditory feedback to participants elicited smaller responses, which suggest the feedforward mechanism was more heavily weighted in comparison to when the participants heard unpredictable auditory feedback (Scheerer & Jones, 2014). Scheerer and Jones' (2014) results support the suggestion that auditory feedback is used differently across situations that vary based on the predictability of presented deviant auditory feedback. This highlights that auditory feedback is used differently based on the presentation of deviant auditory feedback. Thus, this supports the observed lack of relationship between compensatory responses across paradigms in the current research since compensatory responses in the PP did not significantly relate to compensatory responses in the AP.

Based on the results of the current study, it appears that differential weighting of feedback and feedforward inputs leads to the lack of relationship between the compensatory responses across the perturbation and adaptation paradigms. Similarly, pitch and loudness have overlap in the speech system, but are also independent. To show this, Larson, Sun and Hain (2007) had participants produce vocalizations, which were then perturbed in pitch, loudness or both. They found that participants' F0 in response to pitch shifts was large, but the amplitude of the responses was unaffected by pitch shift alterations (Larson, Sun, & Hain, 2007). This suggests that pitch and loudness are independent, although both can be affected by changes to auditory feedback (Larson, Sun, & Hain, 2007). Similarly, the current result suggests that compensatory responses in the PP are not related to compensatory responses in the AP.

Auditory feedback is not only processed differently across paradigms using F0, as was found in the current research. It has also been found to be processed differently using formant frequency based on discrimination ability. In another study conducted by Villacorta et al., (2013), the role of auditory feedback was observed in speech motor learning. The formant frequency of CVC words was manipulated and researchers found that the more participants were able to distinguish vowels the more they were suggested to pay attention to their auditory feedback, and thus the more they compensated (Villacorta et al., 2012). Villacorta et al., (2013) also found that participants with more accurate speech relied more on their sensorimotor representations. This shows how auditory feedback can be processed differently. Just as auditory feedback is processed differently based on vowel discrimination causing a difference in responses, in the current research, auditory feedback is processed differently based on the presentation of different errors.

Perkell et al. (1997) in a review of formant frequency literature explains that it would not make sense to have an auditory feedback control system that was meant to correct for every change in auditory feedback. If this were the case, in an environment where there are many fluctuations in auditory feedback, individuals would constantly compensate for external noises, which would lead to extremely variable vocal productions and unreliable, inconsistent speech (Perkell et al., 1997; Scheerer & Jones, submitted). Instead, speakers have a speech motor control system that allows for relatively stable vocal productions despite environmental changes (Guenther, 2006; Houde & Jordan, 1998; Perkell et al., 1997). The presence of a reflexive speech motor control system like Perkell et al. (1997) described is reflected by the lack of relationship between compensatory responses in the PP and compensatory responses (using median 1500 values) in the AP. Because responses differ based on how errors are presented, it is clear that as Perkell et al., (1997) suggested, there are different roles that auditory feedback plays in vocal production in adults. One role that auditory feedback is used for is for the maintenance of sensorimotor representations, as was measured in the AP. Another is to monitor auditory feedback, as was reflected in the PP. The use of auditory feedback across different contexts shows the efficiency of the speech motor system and sheds light on how the speech motor system operates.

Considering a neural perspective may also help to understand the lack of a relationship between compensatory responses across paradigms we observed. Although the speech system uses feedback control and feedforward control in conjunction to create fluent speech, there are different neural pathways that are activated when the feedback versus feedforward mechanisms are used. Guenther (2006) explains based on his observation of formant frequencies that the auditory feedback control mechanism relies on axonal projections from Broca's area (otherwise known as the frontal operculum) sent to higher order auditory cortical areas. If errors are present, corrections are processed in the posterior superior temporal gyrus and planum temporale through axonal projections from auditory error cells to the motor cortex (Guenther, 2006). Differently, the major brain areas activated by the feedforward system include the axonal projections from the premotor cortex to the primary motor cortex (Guenther, 2006). Motor commands are chosen by the consideration of state information processed by input to the cerebellum by route of pontine nuclei from premotor cortical areas (Guenther, 2006, pg. 360). The feedforward system does not activate the posterior superior temporal gyrus or planum temporale since it, unlike the feedback mechanism, does not process errors (Guenther, 2006). It is clear that different neural activity is responsible for the tasks carried out by the feedback and feedforward mechanisms. From this, it makes sense to have observed different compensatory responses to each of the paradigms. Although each of the mechanisms triggers different neural activity, they still work together to form fluent speech by how each is weighted based on situational demands (Guenther, 2006; Perkell et al., 2006; Scheerer & Jones, 2014). Because the feedback and feedforward systems are differentially weighted based on how vocal errors are presented, different responses were observed when auditory feedback was processed in the FAF perturbation and FAF adaptation paradigms.

In sum, the differential weighting of feedback and feedforward inputs helps to optimize speech for many contexts, particularly through the use of online error correction for perturbation (Bauer & Larson, 2003; Guenther, 2006; Guenther & Vladusich, 2012; Scheerer & Jones, 2012) and speech motor planning for adaptation (Guenther, 2006; Guenther & Vladusich, 2012; Hawco & Jones, 2009; Jones & Keough, 2008; Scheerer & Jones, submitted). Because the PP introduces brief vocal errors after vocalization onset and the AP introduces whole utterance shifts at vocalization onset, participants weight their speech mechanisms differently to accommodate for errors (Hain et al., 2000; Hawco & Jones, 2009). This enables participants to weight their feedback mechanism more for the PP, which plays a role in the stabilization of the voice (Liu et al., 2015; Scheerer & Jones, 2012), and their feedforward mechanism for the AP, which is important for sensorimotor learning and speech motor planning (Jones & Keough, 2008; Scheerer & Jones, submitted), although both systems are used for each paradigm. For these reasons, it makes sense that compensatory responses were not related across paradigms. The observation of how the feedback and feedforward systems are differentially weighted, based on dissimilar presentation of vocal errors, advances our understanding of the speech motor control system and how individual differences affect its responses to FAF.

Variability

The lack of parity found across compensatory responses (indexed by feedback control) to the FAF perturbation and FAF adaptation paradigm does not necessarily invalidate the variability hypothesis. It was hypothesized that there would be a positive correlation between compensatory responses and variability within the FAF perturbation and FAF adaptation paradigms. This research replicated previous literature (Scheerer & Jones, 2012) as it found a positive correlation between compensatory responses and variability within the PP. This means that people who were more variable produced larger compensatory responses to FAF perturbations since they weighted auditory feedback more heavily (Scheerer & Jones, 2012). Differently, individuals who were less variable generally produced smaller compensatory responses and weighted feedback less heavily (Scheerer & Jones, 2012). Based on how participants weight their feedback and feedforward inputs, the variability of participants' habitual F0 influenced individual responses to the FAF manipulation. Because of this, it is important to observe factors like variability that highlight how responses differ in order to learn more about how the speech motor control system functions as a whole. Although compensatory responses were not found to correlate across paradigms in this research, vocal variability is still a good measure for speech motor control and online error correction in the PP.

Despite this, the results of the current study suggest that variability is not a good predictor of compensatory responses in the AP. The present study did not observe a correlation between most variability measures and compensatory responses in the AP. Different from Scheerer and Jones' (submitted) results, in the current research the variability of participants' habitual F0 measured at 80 ms did not significantly correlate with compensation or aftereffects in the AP. The variability of participants' habitual F0 measured at 1500 ms also did not significantly correlate with compensation in the AP.

This means that variability generally does not have the same relationship with compensatory responses produced in the AP as we find in the PP. From this, the relationship between variability does not appear to be consistent across paradigms. To test this, variability was correlated across paradigms. It was found that there was no significant relationship between variability in the PP and variability in the AP. The fact that variability did not correlate across the paradigms is more evidence that auditory feedback is weighted differently across the FAF perturbation and FAF adaptation paradigms.

The result that variability did not significantly relate to compensatory responses in the AP differed from the significant results found in Scheerer and Jones' (submitted) study. However, the parameters in Scheerer and Jones' (submitted) study were not exactly the same as in the current research. In the current research, there were only 10 baseline (unshifted) trials, whereas in Scheerer and Jones' (submitted) study, there were 20 baseline (unshifted) trials. It is possible that the difference in the number of unshifted, baseline trials that were observed made the measure of variability in Scheerer and Jones' (submitted) study more reliable.

Although variability was captured in both paradigms, it is not indexed or calculated in the exact same way across paradigms, which makes it difficult to compare. In the PP, variability is calculated throughout the entire paradigm during intermittently altered vocalizations. Differently, in the AP, variability is calculated during the baseline phase (trials 1-10), before auditory feedback is altered. Because of these differences it is difficult to equally compare variability across paradigms. Although variability is measured differently in the AP, it is known as an adequate way to capture the variability from previous literature (Scheerer & Jones, submitted). To ensure that variability was calculated in an adequate manner in the AP, it was recalculated in an alternative way to see if it would capture the same effect. Based on previous literature (Scheerer & Jones, submitted), variability was originally calculated as the standard deviation of the first 1500 ms of each unaltered vocalization in the baseline phase (trials 1-10). Variability was captured in another way as the standard deviation of random samples of the vocalization every 100 ms of each unaltered vocalization in the baseline phase. This was done to mirror how variability was calculated in the PP as it is measured across each utterance over 100 ms before the vocal alteration (Scheerer & Jones, 2012). In this way, variability was measured moment to moment.

Despite the recalculation of variability to mirror the way it is measured in the PP, variability still cannot be calculated in the same way. Although each paradigm measures variability, because it is observed across paradigms in very different ways, there is disparity in the comparison. This is because in the PP every vocalization is observed, where as in the AP only the first ten vocalizations can be observed. Not only that, in the PP variability is calculated right before each of the four brief alterations to the voice (Scheerer & Jones, 2012). Differently, in the AP, variability is captured across stable, unaltered, whole utterances (Scheerer & Jones, submitted). This difference means that variability can be calculated in every trial during the PP, but only in the first ten trials during the AP. Additionally, the PP could influence variability differently than in the AP as it introduces deviant auditory feedback mid utterance (Liu et al., 2015; Scheerer, Behich, Liu & Jones, 2013; Scheerer & Jones, 2012, 2014). Differently, the AP introduces deviant auditory feedback at utterance onset, after the baseline phase (Burnett, McCurdy & Bright, 2008; Keough, Hawco & Jones, 2013; Keough & Jones, 2008; Scheerer & Jones, submitted). This difference means that variability is measured in the PP while the participant is exposed to FAF trial-to-trial, where as in the AP the participant is not yet exposed to FAF. These fundamental differences not only prevent the calculation of variability in the same way but may also provoke different responses in the PP and the AP.

After calculating variability in an alternative way, the result that variability in the PP did not correlate with variability in the AP remained the same. As well, variability and compensatory responses correlated in the PP but not in the AP. This leads to the conclusion that the way that variability is captured in each paradigm does not correlate across paradigms. This is because each paradigm manipulates FAF in different ways based on the onset of FAF. From this, different responses are elicited from the participants based on how feedback and feedforward inputs are weighted, although both inputs are used. The intermittent deviant auditory feedback in the PP elicits a response that uses more heavily weighted feedback control than feedforward control (Bauer & Larson, 2003; Guenther, 2006; Larson, Burnett & Kiran, 2000; Liu et al, 2015; Scheerer, Behich, Liu & Jones, 2013; Scheerer & Jones, 2012). Since feedback is weighted more heavily, there is increased variability in participants' habitual F0 as they attempt to stabilize their vocalizations from vocal error. Differently, the manipulation in the AP elicits a response that uses more heavily weighted feedforward control than feedback control (Guenther, 2006; Hawco & Jones, 2009; Keough & Jones, 2008; Scheerer & Jones, submitted). This is because FAF is elicited at utterance onset, only after the baseline phase when there is no FAF introduced.

The only measure that showed a significant relationship with the variability of participants' habitual F0 indexed by the first 1500 ms of the vocalization was aftereffects. This means that individuals whose feedback control was more variable produced larger aftereffects. Individuals who are more variable have been suggested to pay more attention to their auditory feedback since it is less predictable (Keough & Jones, 2008; Scheerer & Jones, 2012, 2014). Previous literature has shown that paying more attention to auditory feedback allows speakers to adjust quicker to changes in their auditory feedback and further display smaller aftereffects (Jones & Keough, 2008; Keough, Hawco & Jones, 2013; Scheerer & Jones, submitted). Thus, the participant returns to their normal vocal F0 faster when deviant auditory feedback is removed (Hawco & Jones, 2009; Scheerer & Jones, submitted). Despite this, in this particular instance those who are more variable in their feedback control produced larger aftereffects. It is known that individuals who are more variable weight feedback more heavily than the feedforward system in order to monitor their vocalizations online (Larson, Burnett & Kiran, 2000; Scheerer & Jones, 2012, 2014, submitted). This helps speakers to correct for vocal instability and consequently compensate more than individuals who are less variable (Scheerer & Jones, 2012, submitted). Because individuals who are more variable have been shown to produce larger compensatory responses, it is speculated that individuals in this study who were more variable, specifically with their feedback control, compensated to such an extent that it took longer for them to de-adapt from the FAF manipulation. Due to this, it makes sense that a significant relationship is observed between variability indexed by feedback control (median 1500 values) and aftereffects in the adaptation paradigm.

To observe if there was more parity across paradigms in regards to variability, more correlations were run. Variability in the PP was correlated with compensatory (median 1500) and adaptation (median 80) responses in the AP. It was found that this relationship was not significant and further shows that our measure of variability in the PP is not related to the compensatory responses produced in the AP. This makes sense since the aforementioned results indicated that variability correlated positively with compensatory responses in the PP, but did not correlate with compensatory responses in the AP. Variability was also found not to significantly relate across paradigms. This result, along with the other variability findings, confirms that variability does not relate across paradigms. To further observe parity, or lack thereof, across the paradigms, the relationship between variability in the PP with compensatory (median 1500) and adaptation (median 80) responses in the AP was measured. Another relationship between variability in the PP with aftereffects (indexed by the median 1500 and median 80 values) in the AP was also measured. For both correlations, a significant relationship was not found. Since it was found that variability is not the same across paradigms, it makes sense that the relationship between variability in the PP and compensatory responses as well as aftereffects in the AP do not relate significantly.

In sum, although variability and compensatory responses did not correlate in the AP, variability and compensatory responses did correlate in the PP, which is a replication of previous literature (Scheerer & Jones, 2012). This highlights how the variability of participants' habitual F0 influences their responses to the FAF manipulation based on how they weight the feedback and feedforward systems. There was a non-significant relationship observed between compensation and variability in the AP. Despite this, there was a significant relationship found between aftereffects and variability (indexed by feedback control) in the AP. There was also no significant relationship between variability across paradigms. Additionally, there were no other significant relationships across the FAF perturbation and FAF adaptation paradigms. Due to the differences in the manipulations imposed across the two paradigms, variability cannot be similarly calculated.

Compensatory Responses and Aftereffects in the Adaptation Paradigm

Since it is speculated that individuals who were more variable compensated to such an extent that it took them longer to de-adapt after the FAF manipulation, it makes sense that a significant, positive relationship was found between compensatory responses and aftereffects in the AP. This means that the more a participant compensated, the longer it took for them to de-adapt in the AP. Previous research has found that individuals who are suggested to weight auditory feedback more heavily produce larger compensatory responses and smaller aftereffects (Jones & Keough, 2008). This is because someone who weights auditory feedback more heavily incorporates it more readily into their vocalizations than someone who relies heavily on feedforward input (Burnett, McCurdy & Bright, 2008; Hawco & Jones, 2009; Jones & Keough, 2008; Scheerer & Jones, submitted). The current research has found a different result from previous research, possibly because participants produced very large compensatory responses. Because the participants produced very large compensatory responses (M= 82.13, Range Min.= -283.05, Range Max= 483.67), it may be that it took them longer to de-adapt and adjust their voices from the higher F0 to normal F0. This large compensatory response to FAF when F0 was altered is not a surprise since compensatory responses to altered F0 are known to be larger and often approximate the manipulation (Hawco & Jones, 2009; Keough & Jones, 2009, 2011; Keough, Hawco & Jones, 2013) in comparison to compensatory responses to altered formant frequency, which are often a fraction of the manipulation (Purcell & Munhall, 2006). Despite this significant correlation, there was no significant relationship observed between adaptation responses, which were indexed by median 80 values, and aftereffects within the adaptation paradigm.

Latency

No significant relationship was found between the latency for the onset of the FAF perturbation and the magnitude of compensatory responses in the PP. This means that the amount of compensation produced in response to the shift does not affect the speed of response to the alteration. Despite this, a significant relationship was found between response latency for the maximum compensation magnitude and compensatory responses. Therefore, the more a participant compensated in response to the FAF manipulation, the quicker they reached their maximum compensatory response within the vocalization. There was also an observed relationship between variability and response latency in the PP. This means that the faster a participant responded to the FAF manipulation, the more variable they were. This makes sense because individuals who are more variable pay more attention to their auditory feedback (Scheerer & Jones, 2012). If speakers pay more attention to their auditory feedback, they incorporate it into their vocalizations more readily, and thus may respond faster to it.

To observe if the speed of response to FAF relates to variability across paradigms as it does within the perturbation paradigm, the relationship between latency measures in the PP and variability measures in the AP were investigated. In both paradigms, individuals who weight their auditory feedback more heavily have been suggested to be more variable (Scheerer & Jones, 2012, 2014, submitted). From the lack of correlation between latency measures in the PP and variability measures in the AP, it is appears that individuals who respond faster to FAF in the perturbation paradigm are not more vocally variable in the AP. Although individuals who weight auditory feedback more heavily generally respond quicker to it (Scheerer & Jones, 2014, submitted), the lack of correlation observed could be because of the lack of parity, specifically in regards to variability across paradigms. As was mentioned previously, variability is calculated differently across the paradigms due to the differences in how the manipulations are imposed across paradigms. Just because individuals respond quickly in the PP, which indicates that they weight their auditory feedback more heavily, does not mean that they use auditory feedback in the same way in the AP. Thus, latency in the PP is unrelated to variability in the AP.

The relationship between latency in the PP and compensation, as well as aftereffects in the AP were investigated to observe if there were more sources of parity across the paradigms. The correlation between response onset latency in the PP and compensation in the AP was not significant. The correlation between response onset latency in the PP and aftereffects in the AP was also not significant. Due to the lack of correlation across paradigms, it appears that latency in the PP is not related to compensation or aftereffects in the AP. This means that the speed at which participants reach their maximum response to FAF in the perturbation paradigm is not related to how auditory feedback is used to produce compensatory responses or de-adapt in the AP. Since auditory feedback is differentially weighted across different contexts (Burnett, McCurdy & Bright, 2008; Jones & Keough, 2008; Keough, Hawco & Jones, 2013; Scheerer & Jones, 2014), it makes sense that the way auditory feedback is used across paradigms produces unrelated responses.

Previous literature has observed how factors such as predictability, language experience and vocal experience affect response latency in the PP. Despite this, few formant frequency studies have observed how response latency relates to other measures. Nonetheless, there have been many studies that have found that the predictability of auditory feedback leads to faster vocal responses (Burnett, McCurdy & Bright, 2008; Scheerer & Jones, 2014). Other studies like one conducted by Xu et al. (2004) investigated how tones affect the latency of responses to F0 shifts. They found that tonal language speakers (such as Mandarin) responded faster to F0 shifts in dynamic tones but not static tones. Another study conducted by Burnett and Larson (2002) observed how vocal experience affects the latency of responses to F0 shifts. They found similar results as Xu et al. (2004) as they observed that singers responded faster to dynamic tones rather than steady ones (Burnett and Larson, 2002). This shows that response latency changes based on language experience and vocal experience. Despite these significant results, no previous studies have observed the relationship of response latency in the PP in comparison to compensation, or any other measures, in the AP. Because the previous literature had observed response latency within a paradigm, and not across, it is difficult to use their results to make parallels to the current research. In sum, the result in this thesis, that response latency in the PP is not related to responses in the AP, is another piece of evidence that displays a lack of parity in how auditory feedback is used across paradigms. This further supports the theory that auditory feedback is weighted differently across paradigms.

To determine the relationship between timing of responses to the FAF manipulation in the perturbation paradigm and learning, response latency measures in the PP and learning measures (the slope of median 80 and median 1500 values) in the AP were observed. The relationship between response onset latency measures in the PP and rates of learning in the AP, specifically for median 1500 values, was not significant. This means that how quickly a participant responded to the FAF manipulation in the PP was not related to the rate of learning in the AP.

Differently, the relationship between response onset latency in the PP and rates of learning in the test phase of the AP, specifically for median 80 values, was significant. Thus, the faster a participant responded to the FAF manipulation in the perturbation paradigm, the longer it took them to de-adapt in the test phase (the last ten unaltered trials) of the AP. This result is consistent with previous findings that the more participants compensated in the AP the longer it took them to de-adapt in the AP. It is possible that participants who compensated quickly to the FAF manipulation in the perturbation paradigm also compensated largely across paradigms, and therefore took more time to unlearn from the deviant auditory feedback that was presented to them. This makes sense since median 80 values reflect feedforward control, which indexes sensorimotor learning (Keough, Hawco & Jones, 2013; Scheerer & Jones, submitted). Although response latency in the PP does not relate to rates of learning in the adaptation paradigm indexed by the slope of median 1500 values at the end of the training phase, it does correlate with rates of learning indexed by the slope of the median 80 values.

Learning

To investigate how measures of learning relate to both aftereffects and compensation, the slope of median 80 and median 1500 values were observed. No relationship was found across compensatory responses in the AP (indexed by median 1500 values) with the slope of median 80 values. Additionally, no relationship was found across aftereffects in the AP and slope of median 80 values across shifted trials (trials 11-15). However, there was a marginally significant negative relationship between compensatory responses in the AP, indexed by the median 1500 values, with the slope of median 1500 values during the test phase. Although this relationship was only marginally significant, it is still important to highlight. This relationship means that larger compensatory responses in the AP were related to smaller aftereffects when participants F0 was returned to their baseline F0. This is in agreement with other research that has demonstrated that individuals who rely more on feedback and produce larger compensatory responses do not adapt as strongly (Jones & Keough, 2008; Keough & Jones, 2009) and use their feedback to quickly ‘unlearn’ any changes to sensorimotor representations. With that being said, there was a significant positive relationship found between aftereffects and the slope of median 1500 values (indexing feedback control) at the beginning of the altered trials (trials 11-15). This means that the faster individuals learned to compensate to the shifted trials (trials 11-15) in the AP, the larger aftereffects they displayed when they heard their auditory feedback reverted back to their true F0. This seems to conflict with the finding that larger compensations is indicative of greater weighting of feedback. However, participants with a steeper median 1500 slope may have produced smaller compensatory responses overall, but used the feedback to update their sensorimotor representations, and this adaptation response is included in the median 1500 measure. These individuals would have in turn produced larger aftereffects due to their increased sensorimotor learning.

Gender

There are differences anatomically between males and females, especially within speech related areas. For example, the female larynx is known to be smaller than males’ (Titze, 1989). Although previous speech studies have not shown notable gender differences to FAF stimuli through the measurement of formant frequencies, previous literature has shown gender differences in response to FAF stimuli in regards to F0. For example Chen et al., (2010) found that in response to the FAF manipulation, males showed a larger magnitude and latency in their responses. This study suggested that there may be a difference in how FAF is processed between males and females (Chen et al., 2010). Liu et al. (2012) confirmed the previous result and reported that males display larger response magnitude to the FAF manipulation in comparison to females. Despite this overlap, in another study, Scheerer, Liu and Jones (2013) did not find gender differences in response magnitude, but alternatively observed that females (on P1, N1, P2 components) responded faster than males to the FAF manipulation neurally and behaviourally, a result not found by Liu et al (2012), but confirmed by Chen et al., (2010). Due to the observed effects of gender that were both confirmed and conflicted in previous literature, effects of gender were investigated in this research. There were no significant effects of gender found in the current study.

Conclusion

The aim of this thesis was to establish if the responses produced after auditory feedback manipulations during the FAF perturbation and FAF adaptation paradigms are related. It was predicted that there would be a positive correlation between compensatory responses in the FAF perturbation and FAF adaptation paradigms and a negative correlation between compensatory responses and aftereffects in the AP. This study found that there was no relationship between compensatory responses in the PP with compensatory responses in the AP. It was also found that within the AP, compensatory responses and aftereffects correlated positively. Overall the results suggest that auditory feedback is used in an unrelated manner across the different contexts provided by the FAF perturbation and FAF adaptation paradigms. Where the PP allows for the observation of reflexive responses, the AP allows for the measurement of sensorimotor learning. Thus, responses to each paradigm are not regulated in the same way.

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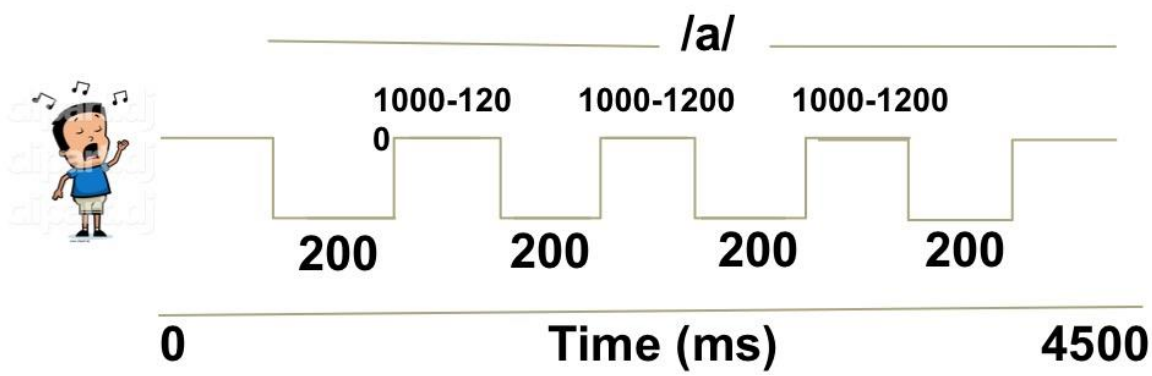
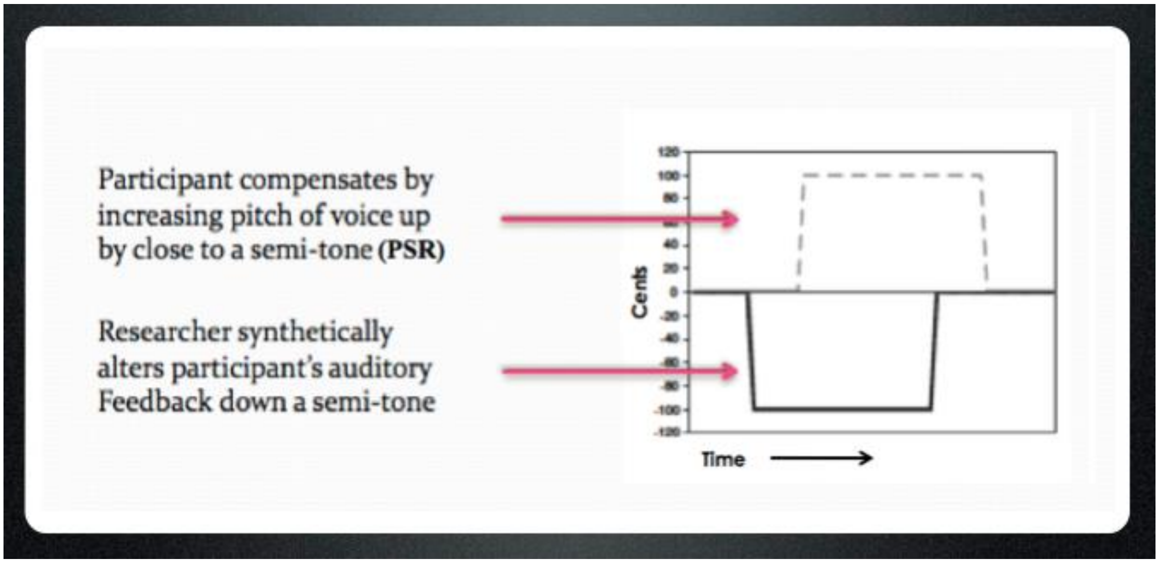
Figures

Figure 1: The Perturbation Paradigm



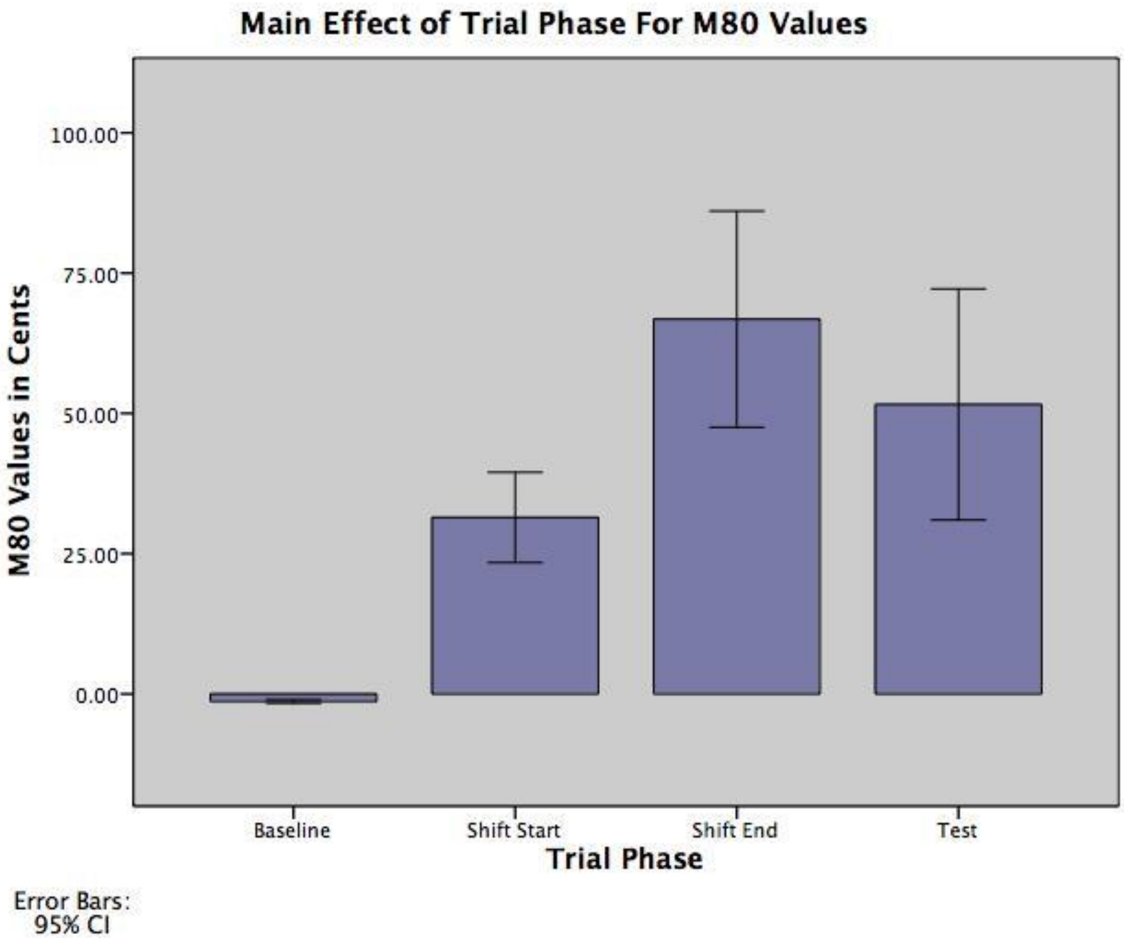
Within the FAF perturbation paradigm, brief and unexpected changes to a speaker's auditory feedback are induced. When the participant produce their vocalization (an /a/ sound), the voice is shifted four times for 200 ms each perturbation. In between perturbations the voice is returned to normal F0 for approximately 1000 ms.

Figure 2: The Pitch Shift Reflex



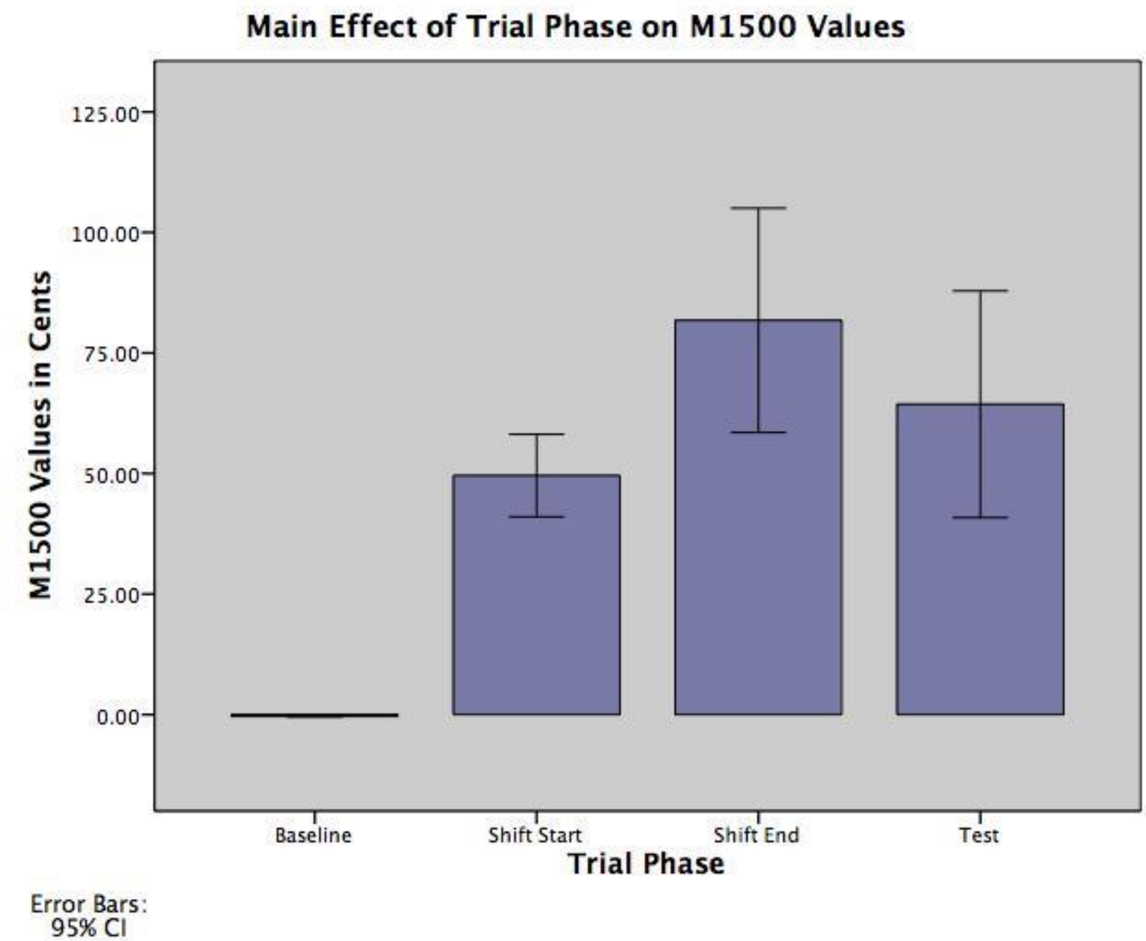
The pitch shift reflex (PSR) is elicited when a speaker's auditory feedback is altered in frequency (frequency altered feedback; FAF). It is an automatic compensatory response that occurs in the opposite direction of the FAF.

Figure 3: Main Effect of Trial Phase For M80 Values



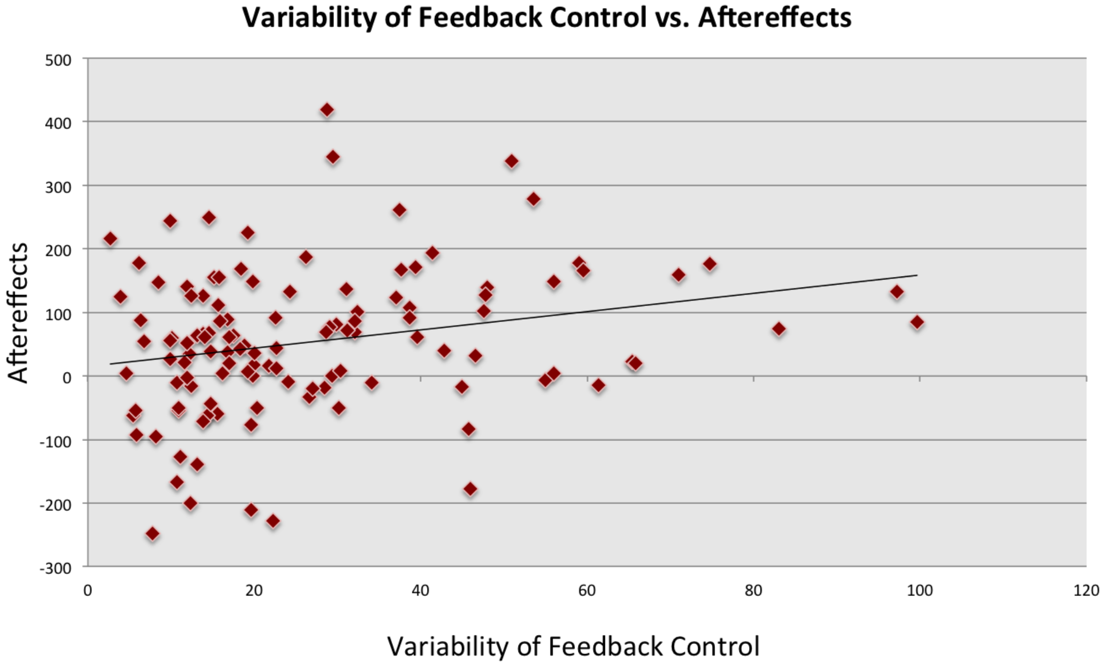
This figure denotes the average F0 (fundamental frequency) values for the first 80 ms of each vocalization. Each of the four data points represents a trial phase. The baseline phase represents the average of trials 1-10, The shift start phase represents the average of the first 10 trials in that phase (trials 11-20). The shift end phase represents the average of last the ten shifted trials in that phase (trials 81-90). Trial phase 4 represents the average of the last ten vocalizations (trials 91-100), or in other words, test phase. The shifted phase (trials 21-90) consisted of each vocalization being synthetically altered down one semi tone (-100 cents) for the entire utterance.

Figure 4: Main Effect of Trial Phase For M1500 Values



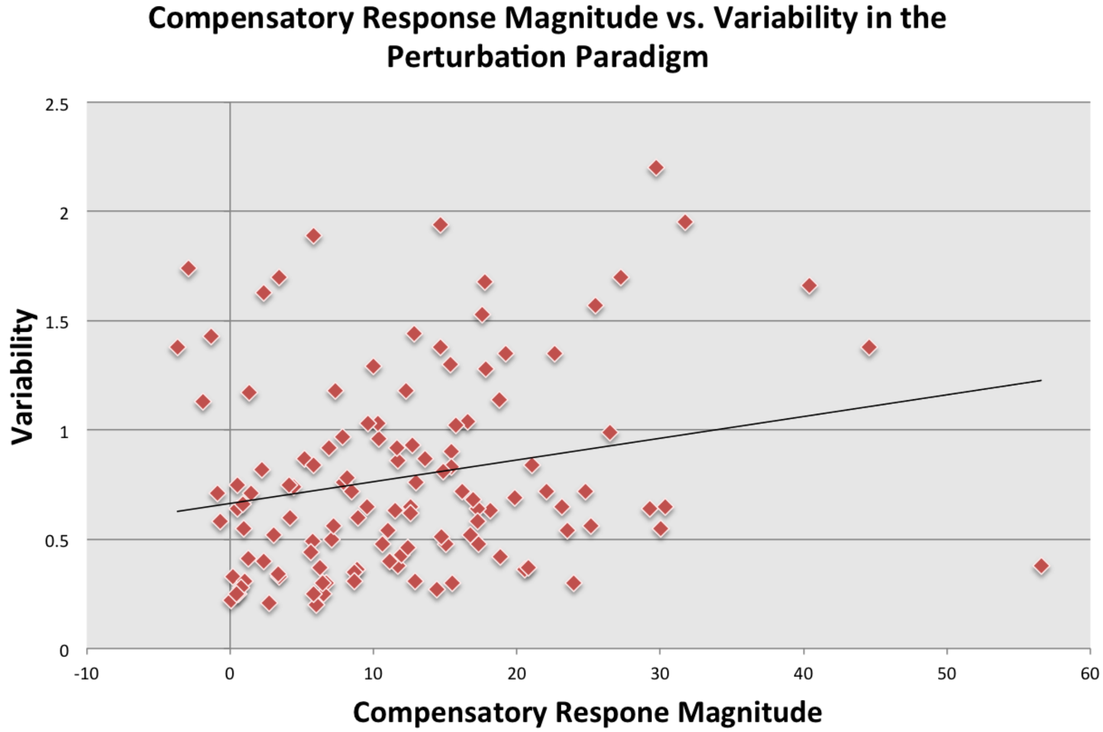
This figure denotes the average F0 (pitch or fundamental frequency) values for the first 1500 ms of each vocalization. Each of the four data points represents a trial phase. Trial phase 1 represents the average of the first ten trials (trials 1-10), or in other words, the baseline phase. Trial phase 2 represents the average of the first ten shifted trials (trials 11-20), also called the shift start phase. Trial phase 3 represents the average of last the ten shifted trials (trials 81-90), which is the shift end phase. Trial phase 4 represents the average of the last ten vocalizations (trials 91-100), or in other words, test phase. The shifted phase (trials 21-90) consisted of each vocalization being synthetically altered down one semitone (-100 cents) for the entire utterance.

Figure 5: Correlation Between Variability of M1500 Values and Aftereffects



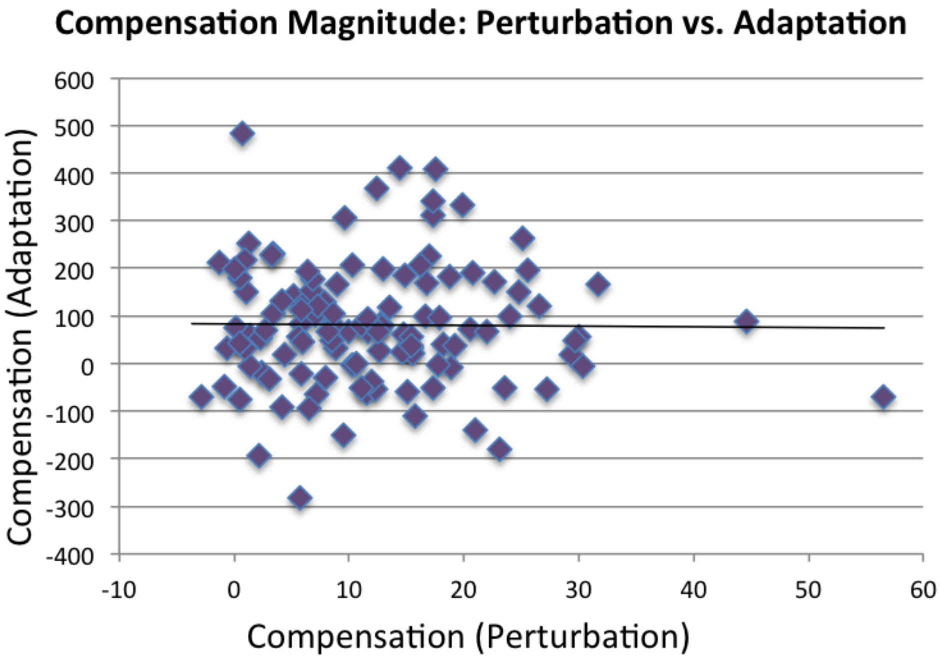
There is a correlation between the variability of M1500 (feedback control) and aftereffects ($r(118) = .245$, $p = .007$). This shows that individuals who are more variable have larger aftereffects.

Figure 6: Correlation Between Compensation and Vocal Variability Within the FAF Perturbation Paradigm



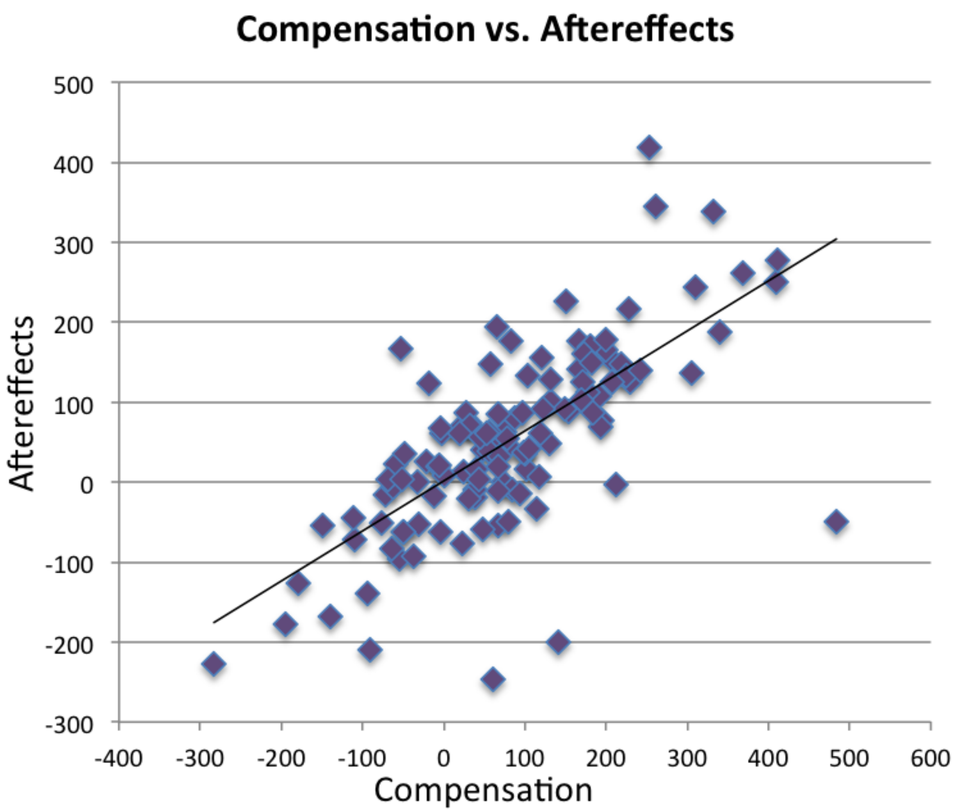
There is a correlation between compensatory responses and variability within the FAF perturbation paradigm (r(120) = .221, p = .015). This shows that individuals who compensate more are more variable.

Figure 7: Correlation Between Compensation Responses in the Perturbation and Adaptation Paradigms



There is not a correlation between compensatory responses in the FAF perturbation paradigm and compensatory responses in the FAF adaptation paradigm ($r(113) = -.011$, $p = .903$). This shows that there is no relationship between the use of auditory feedback in the FAF perturbation versus FAF adaptation paradigms.

Figure 8: Correlation Between Compensation and Aftereffects Within the FAF Adaptation Paradigm



There is a correlation between compensatory responses in the FAF adaptation paradigm and aftereffects ($r(119) = .705$, $p<.001$). This shows that individuals who compensate more also have larger aftereffects.

Appendix A

WILFRID LAURIER UNIVERSITY

INFORMED CONSENT STATEMENT

The Effects of Altered Auditory Feedback on Vocal Production Throughout the Lifespan

Dr. Jeffery Jones, Cognitive Neuroscience of Communications Lab, Department of Psychology

Nichole Scheerer, PhD Student, Department of Psychology

Dani Jacobson, MSc Student, Department of Psychology

The purpose of this study is to investigate how changes in auditory feedback alter perception and vocal production.

INFORMATION

You are invited to participate in this study, which will take about 60 minutes at Wilfrid Laurier University. For this experiment you will be asked to produce vocalizations (vowel sounds). During this experiment you will wear a microphone and headphones, which will allow your voice to be recorded and played back as you speak. While you are vocalizing the pitch of your feedback may be altered for brief periods. This information will be recorded. The results of this study will allow us to investigate the influence of auditory feedback on vocalizations in adults.

You are also asked to complete a Handedness and Language Questionnaire (attached), which should take no longer than 5 minutes.

This research is being conducted by Nichole Scheerer (PhD student), and Dani Jacobson (MSc student), as part of the MSc thesis requirements for Dani Jacobson, under the supervision of Dr. Jeffery Jones. Your data will only be viewed by Dr. Jeffery Jones, Nichole Scheerer, and Dani Jacobson.

CONFIDENTIALITY

Each participant in this experiment will be assigned a participant ID code that will be attached to all data. The only way this ID will be associated with the participant is on their consent form and questionnaires, which will be locked in the Jones lab and only accessible to Dr. Jeffery Jones, Nichole Scheerer, and Dani

Jacobson. During this experiment participants' will be recorded. However, the recordings will not include any personal information, nor will they be associated with the participant in any way other than their ID code and date of collection. Once the study is completed, all data will be removed from the computer and will be stored on a secure server. The data and the questionnaires will be kept in a cabinet in a secure room for an indefinite period of time. Once data collection is completed (no later than July 1, 2016), consent forms will be destroyed by Dr. Jeffery Jones. If the data and questionnaires are ever disposed of, Dr. Jeffery Jones will securely delete the data and shred the questionnaires. No names will be attached to any publication or figures associated with this study. All analyzed data will be associated with the participant's code.

RISKS

There is also a risk of boredom during the experiment, you may choose to leave the experiment at any time.

BENEFITS

As a participant in this study, you may benefit by learning how experimental research is conducted in cognitive psychology. The information obtained in this study will provide important information on how children and adults control their voice.

COMPENSATION

For participating in this study you will have the option be compensated with 1 PREP credit for your time and participation.

CONTACT

If you have questions at any time about any study or the procedures, (or you experience adverse effects as a result of participating in any study) you may contact the researcher Dani Jacobson (email: jaco9590@mylaurier.ca), or their supervisor Dr. Jeffery Jones (phone: 519-884-0710, extension 2992; email: jjones@wlu.ca). This project has been reviewed and approved by the University Research Ethics Board at Wilfrid Laurier University. If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Dr. Robert Basso, Chair, University Research Ethics Board, Wilfrid Laurier University, (519) 884-0710, extension 4994 or email rbasso@wlu.ca.

PARTICIPATION

Your participation in this study is voluntary; you may decline participation without penalty. If you decide to participate, you may withdraw from the study at any time. If you withdraw from the study early, your data will not be transcribed or coded, nor used in the analyses of the study. You have the right to omit any question(s)/procedure(s) you choose without penalty or loss of benefits to which you are otherwise entitled.

FEEDBACK AND PUBLICATION

The interim results of this research will be posted on the psychology bulletin board by March 25, 2016. If you would like to receive feedback from this study please include your email address below. Feedback will be emailed to you following the completion of data collection by July 1, 2016. Findings from this study will be included in either Nichole Scheerer or Dani Jacobson's thesis; however, your data will be reported only as part of a group mean in this and any other documents or publications that arise from this research, such as presentations and journal articles (i.e., you will not be publicly identified).

CONSENT

I have read and understand the information given on page 1 and 2 and received a copy of this form. I agree to participate in this study.

Date of Birth _ _/_ _/_ _ (MM/DD/YY)

Gender: Male / Female (circle one)

Signature___________________________________ Date______________

Email Address:
____

Language Questionnaire

Gender: Male Female Other

Age: ------------________________________________

Years of Education: ________________________________

1. What is the first language you learned?

2. What other languages do you know?

3. What is your best language for speaking?

4. What is your best language for writing?

5. What language(s) did your family speak at home?

6. In what city (and country) were you born?

7. How long did you live in the city that you were born?

8. In what city did you go to elementary school?

9. In what city did you go to highschool?

10. How many years have you lived in Canada?

11. Do you have any formal musical training (vocal or instrumental)? If so, please indicate when you received this training and how many years you studied.

Handedness Questionnaire

Instructions: Think carefully about each of the following tasks and indicate by circling, whether you use your left hand, right hand or either hand.

1. Which hand do you use to hold scissors?

Left Either Right

2. With which hand do you draw?

Left Either Right

3. With which hand do you screw the top off a bottle?
Left Either Right

4. With which hand do you deal cards?

Left Either Right

5. Which hand do you use to hold a toothbrush when cleaning teeth?

Left Either Right

6. With which hand do you use a bottle opener?

Left Either Right

7. With which hand do you throw a ball away?

Left Either Right

8. Which hand do you use to hold a hammer?

Left Either Right

9. With which hand do you thread a needle?

Left Either Right

10. With which hand do you hold a racket when playing tennis?

Left Either Right

11. With which hand do you open the lid of a small box?

Left Either Right

12. With which hand do you turn a key?

Left Either Right

13. With which hand do you cut a cord with a knife?

Left Either Right

14. With which hand do you stir with a spoon?

Left Either Right

15. With which hand do you use an eraser on paper?

Left Either Right

16. With which hand do you strike a match?

Left Either Right

17. With which hand do you write?

Left Either Right