Critical Review: What is the effect of manipulating Fo pitch of auditory feedback on pitch production in normal hearing individuals?

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This critical review examines the changes which occur in speech production when the Fundamental Frequency (Fo) is increased or decreased compared to the individual's natural Fo. Auditory feedback plays an important role in speech because the individual uses the sounds of their voice to calibrate and self-monitor speaking volume, vocal pitch and articulation to ensure the speech outcome is consistent with the intended message. Three reviewed studies were identified as within group repeated measures designs. With an increase in auditory feedback Fo, there was a downward shift in the Fo of the speech output. The opposite was true when there was a decrease in the Fo auditory feedback.

Introduction

Auditory feedback is used by everyone since it has an important role in the individual's ability to monitor their vocal output. Normal hearing speakers often attempt to speak louder in noisy conditions to improve their ability to use auditory feedback to self monitor (Ringel & Steer, 1963). This is known as the Lombard effect (Lee, Lee, Ban, Lee, Jin, 2008). When the auditory feedback pitch of an individual's voice is altered, the individual will attempt to compensate (Burnett, Freedland, Larson & Hain, 1998). Altered auditory feedback explains why postlingually deafened people experience deterioration of voice Fo and amplitude control shortly after the onset of hearing loss (Jones & Munhall, 2002). Clinically, an audiologist will see that post-lingually deafened individuals will have problems monitoring their own voice, and will have difficulty producing normal intonations. This occurs because they lose part of the ability to monitor their own voice. Self monitoring is essential to assure proper clarity and agreement with the intended message. Thus, throughout conversations every individual will monitor their own pitch, loudness, quality, and rate of speech.

Studies investigating the effects of auditory feedback change the way the individual hears him/herself and then measures vocal pitch to determine whether there is any compensatory change in vocal pitch. Some studies have demonstrated that the voice fundamental frequency (Fo) is monitored and controlled through a closed-loop negative feedback system. When the Fo is artificially increased or decreased, subjects change their Fo in the opposite direction to compensate for the difference between he perceived and the intended pitch (Donarth, Natke, Kalveram, 2002). The negative feedback system allows the individual to compare the perceived pitch to an internal reference and then adjust the Fo output in the opposite direction accordingly. There is also evidence that auditory feedback is controlled through an open-loop (Larson, Burnett, Kiran &Hain, 2000).

Objectives

The primary objective of this review is to analyze and critically review the existing literature in the area of Fo auditory feedback. Primarily, our objective is to examine the differences between increasing or decreasing the Fo. Lastly, the recommendations and clinical implications of this research will be discussed.

Methods

<u>Search Strategy</u>
Computerized search databases including PubMed, SCOPUS and CINAHL were searched using the following key words:

> ((Auditory feedback) AND (pitch-shift) AND (Fo) OR (fundamental frequency))

A limitation applied was (English)

<u>Selection Criteria</u>
The studies selected for inclusion in this critical review were required to investigate the impact of altering voice Fo in an increasing or decreasing direction in relation to the individual's natural Fo. Furthermore, the Fo of the vocal stimuli did not include an anticipatory change in Fo. Thus, the participants were unable to anticipate and compensate for the Fo pitch shift prior to the stimuli alteration. All studies were required to include participants who had English as their first language. The age of the research participants was limited to adults over the age of 18 and participants were required to have normal hearing without a history of speech or language problems.

Data Collection

Results of the literature search yielded the following types of design consistent with the previously stated criteria: With group repeated measures which have a level 2 of evidence.

Results

The apparatus was very similar for all within group experiments examined. The subjects typically sat in a sound treated room and vocalized a predetermined utterance. Utterances were recorded using a microphone and then filtered and amplified before they were sent to a recorder. A harmonizer then transformed the pitch of the signal accordingly. To reduce the impact of natural acoustic feedback through bone conduction, the pitch-shifted signals were mixed with 75 dB SPL pink noise and multi-speaker babble (Jones & Munhall, 2000), 40 dB SPL pink noise (Larson, Sun & Hain, 2007) or 40 dB SPL low pass filtered masking noise (Chen, Liu, Xu & Larson, 2007) Subjects received their own altered auditory feedback amplified through insert (Jones & Munhall, 2000) or Sennheiser headphones (Chen et al. 2007 & Larson et al., 2007). The pitch shifting process introduced a small delay of 3-4 ms (Jones & Munhall, 2000) or 14 ms (Larson et al., 2007). The subjects attempted to keep their vocal level near 70 dBSPL (Chen et al. 2007 & Larson et al., 2007) and vocalize for 5 sec (Larson et al., 2007 & Chen et al.2007) or 3 sec (Jones & Munhall, 2000). The participants reported normal hearing with no speech or language problems or neurological disorders.

Jones and Munhall's (2000) within group design implemented a slowly changing pitch shift to address the role played by acoustic feedback in the control of voice Fo. They also examined whether voice Fo is controlled relative to an internally represented reference frequency. In this study, 18 subjects sat in a room and vocalized the vowel /α/. They received their voice feedback in 3 different conditions; a shift-up, shift-down or control condition. The presentation order of each condition was counterbalanced and delivered on different days to avoid vocal fatigue. First each subject produced 10 utterances which were unaltered to achieve a baseline. 100 utterances were then completed in which the pitch of their voice was altered by one cent after each utterance. Following these trials, 20 utterances were recorded where the feedback was maintained at the + or -100 cents. Finally, 10 trials were recorded where the feedback was unaltered. Results were analysed using an ANOVA which revealed a significant change in observed Fo when the Fo of the auditory feedback was changed away from the baseline value. When the Fo in the auditory feedback was increased, or shifted-up, the Fo of speech output decreased to compensate for the pitch shift. Also, when there was a decrease in the Fo of auditory feedback, there was an upward shift in Fo for speech output. The Fo reached its maximum amplitude at 100 cents before it began to converge back to the control value. The shift-up condition started to diverge away from the control condition earlier than the downward-shift condition. After normal feedback was implemented, the subjects completing the shift-up condition experienced an increase in voice Fo. Also, the subjects completing the shift-down condition experienced a decrease in Fo following return to normal feedback. These results indicate that there is a compensation effect which occurs in an attempt to maintain voice Fo. Furthermore, the subjects showed an adaptive effect once they returned to unaltered auditory feedback. This suggests that an internal model plays a role in the long-term calibration of vocal pitch independent of direction of pitch-shift direction.

One limitation to this study is that the researchers did not control for vocal intensity. This is important because previous research has revealed that increases in vocal intensity also correspond to increased vocal Fo. However, to determine if the observed results were due to changes in speaking intensity, the researchers compared the root-mean-square amplitude of the vowel pre and post test. The ANOVA proved that the pitch changes associated with a change in Fo were not affected by training time or vocal intensity. Furthermore, since testing took place on different days, the changes between upward pitch-shift and downward-pitch shift may not have been consistent across days. Lastly, the increase in pitch during the control condition implies that vocal fatigue occurred which may have impacted the Fo.

Larson, Sun and Hain's (2007) within group design investigated the effects of altering the auditory feedback Fo of voice pitch, loudness or a combination of the two conditions to a group of 24 participants. The subjects vocalized the vowel /u/. Changes in voice Fo and amplitude were measured in response to either pitch-shifted or loudness-shifted voice feedback. The trials were completed with each condition individually or a combination of the two conditions either changing in the same or different direction. Response latencies and magnitudes were statically analyzed with one-way ANOVA's. Results indicated that 11% of the trials produced "Following" responses for both the shift-up and shift-down conditions. When the pitch Fo was altered in the downward-shift direction, there was a slight compensatory change in the subjects voice Fo. Under the same condition, the researchers recorded smaller amplitudes when compared to the shift-up condition. When the Fo was shifted up, there was a decrease in the Fo recorded indicating that a compensatory effect occurred. Accordingly, there was an increase in amplitude when compared to the shift-down condition. During both the shift-up and shift-down conditions, the response magnitude was similar. The direction of the Fo shift did not alter the results when combined with a change in loudness since the amplitude response to the +50 cent -3dB stimulus was much smaller than the response to the -50 cent +3 dB. The direction of Fo shift did not produce a significant change in the Fo response latencies. Furthermore, the direction of Fo shift did not produce a significant change in voice amplitude response latencies. This data suggests that Fo and loudness of Fo share neural circuitry and are intertwined until being decoded in the auditory cortex since there was no consistent change in Fo across the interactions. Nevertheless, under simultaneous conditions, they can function independently. It was concluded that subjects perceive an increase in Fo to be greater than a decrease in Fo and thus, nonlinear interactions exists between the direction of change of inputs and the size of the response.

In this study, order effects were not controlled. Only a portion of the data was analyzed which may prevent the reader from obtaining reliable results since bias could have been introduced. Baseline measures were not mentioned so, it is unclear how the participants perform with no alterations in Fo auditory feedback. Since all the testing was done in one session, vocal fatigue may have affected the Fo amplitude and pitch responses since vocal fatigue produces a corresponding rise in intensity.

Chen, Liu, Xu & Larson's (2007) study evaluated the voice Fo response to pitch shifted auditory feedback during a sustained vowel task and a speech task. The purpose of the study was to test whether the response magnitudes or latencies to pitch-shifted voice feedback are modulated during English speech. 20 subjects were instructed to repeat both a phrase in the form of a question as well as the vowel /u/. The three conditions tested were +-50 cents, +-100 cents and +-200 cents. During each of the 12 utterances, the Fo of the vocal output was randomly altered 5 times in a shift-up direction, pitch-down direction, or was unaltered. During the 12 utterances, the pitch-shift magnitude was consistent. Results were averaged and a point-by-point series of t-tests were run between each control wave and each test wave. A "difference" wave was then created by subtracting the average control wave from the upward or downward test wave. Response latencies and response magnitudes underwent statically analysis using a repeated-measures ANOVA was completed to determine if any significant interactions were present. When compared to the speech task in which an increase in stimulus magnitude produced an increase in response magnitude, the vowel task did not show the same trend. However, the response magnitudes were slightly smaller for the shift-up condition indicating that a compensating response was not as great. During the shift-down condition there was a higher degree of variation in the response magnitude when compared to the shift-up condition in which most of the results fell close to the median. Results confirmed that responses to pitch shifted feedback during speech were larger and faster than those produced during a sustained vowel task, regardless of pitch shift direction.

A limitation to this study is that during each utterance, the Fo was altered 5 times rather than having one condition tested during each utterance. Since previous research has shown that there are adaptive effects with shifts in Fo, the results could have been altered due to the previous stimulus. Also, the pitch-shift stimulus was not slowly modified, and the participants may have noticed the Fo of their voice changing. Thus, participant bias may have occurred. Since testing took place on the same day, vocal fatigue may have influenced the results since vocal fatigue results in an increase in vocal Fo.

Conclusion/ Recommendations

The present evidence suggests that an upward shift in Fo feedback results in a decrease in the Fo of speech output. Likewise, decreasing the pitch Fo of auditory feedback produces an increase in speech Fo output. This outcome has been consistent across several studies. However, in some cases, there is a following response in which a decrease in auditory Fo feedback results in an increase in Fo for speech production. The following response was only observed in a minority of the trials. The following response still needs to be examined in more detail since it is still unknown why this phenomenon sometimes exists.

The current available literature is suggestive of an opposing relationship between increasing and decreasing the Fo of auditory feedback. In each case, the responses to altered Fo auditory feedback occur within 200 ms, regardless of shift direction. Also, similar response magnitudes were recorded regardless of pitch shift direction in most of the research. However, Chen et al. (2007) observed that if there was an increase in auditory feedback Fo, the response magnitude was slightly smaller, but these results were not found to be significant. Contradicting what Chen et al. discovered, Larson et al, measured less of an amplitude response for a decrease in Fo auditory feedback pitch. Jones & Munhall measured similar results when they discovered that with an increase in Fo auditory feedback, the subjects diverged from the control condition earlier than if there was a decrease in auditory feedback Fo. Also, when the auditory feedback Fo was increased and returned back to normal, there was a greater change in the cents of speech production with an increase in Fo compared to the condition where the Fo auditory feedback was decreased.

Clinical Implications

This evidence implies that if a short term change in pitch Fo is needed, the individuals vocal pitch should be heard with a increase in Fo pitch shift since a decrease in Fo pitch shift does not produce as much of a change. This may be helpful in treating speech disorders where the desired outcome is a decrease in speech Fo. Also, treatment plans should implement speech as the vocal stimuli rather than sustained vowel tasks since altering the Fo of speech produces greater response magnitudes compared to a sustained vowel task.

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