Modulation of Relative Fundamental Frequency During Transient Emotional States

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Summary: Relative fundamental frequency, a measure of the muscular and aerodynamic influences of voicing offset and onset of vowel-voiceless consonant-vowel production, has been known to reflect conditions of vocal hyperfunction and serves as a measure that might be influenced by transient emotional states. Twenty-six vocally healthy females underwent aversive, neutral, and positive emotional induction while saying /afa/. Results show that individuals had a steeper fundamental frequency decline on the 10 cycles of offset of vocalization during positive and neutral conditions than aversive conditions. Individuals had an overall elevated fundamental frequency curve during the 10 cycles of vocalization onset in positive conditions. Findings suggest that the vocal offset reflected reduced muscular engagement in positive and neutral conditions compared with aversive conditions, suggesting that aversive emotional influence on voicing has a muscular component.

Key Words: Emotion−Voice−Relative Fundamental Frequency−Psychology−IAPS.

INTRODUCTION

There is a growing body of converging evidence in the literature that suggests that emotions affect vocal output.[1−5] Understanding how emotional states affect vocal output sharpens our understanding of how temperament can lead to voice disorders[6,7] and compels us to consider emotions and temperament in voice treatment. Additionally, recognizing the role emotion plays in vocal output can refine our interpretation of important constructs such as vocal effort[1,8,9] and could potentially influence the interpretation of measures of maximum ability such as maximum phonation time or voice range profiles.[10]

Some research has sought to quantify unique vocal signatures of various emotional states such as anger, fear, and joy.[11] Other research has investigated the physiological responses of an individual during emotional states and how these physiological changes influences voice production. This physiologically-based line of research suggests that the voice presents with increased muscular activation (ie, hyperfunction) during conditions of negative affect and higher arousal (negative emotions, stress in fearful conditions, etc.).[2−5] This effect is observed as an increase in electroglottographic contact quotient,[2,3] increased laryngeal resistance,[12] and increased laryngeal electromyography.[5] Conversely, positive and neutral conditions have resulted in less physiological changes and there is little evidence that positive emotions can be completely differentiated from neutral emotions.[2,3]

Because of the expanding corpus of data suggesting that increased muscular activation varies with emotional states, additional measures of muscular hyperfunction should also show modulation with emotional. One such measure is relative fundamental frequency (RFF).[13] RFF is the change in fundamental frequency observed in vowels immediately adjacent to voiceless obstruent consonants. RFF contains two components: the offset, when the voice is turning off for the voiceless consonant; and the onset, when the voice is turning on to resume vowel (or voiced consonant) production.[13] Phonatory offset and onset reflects the fine-tuning of the vocal system;[14] therefore, its fluctuation in various context may be more appropriate to assess variations in fundamental frequency not attributed to other social or linguistic contexts (eg, prosody).[15]

The underlying theory behind RFF is elegantly described by Stepp et al[13] who found that RFF separated individuals with vocal hyperfunction from healthy controls. They compared 100 individuals with hyperfunction to 15 control participants and found that those with hyperfunction had lower vocal offset and onset. The phonatory influences of vocal offset and onset are believed to be both muscular and aerodynamic.[16] For both the offset and the onset, Watson[16] theorized that the muscular tension of the cricothyroid (CT) present during voiceless consonants generates increasing F_O in anticipation of offset and carries over following initiation of subsequent voicing. For the offset, there is also an accompanied reduction in F_O because the vocal folds are abducting which reduces airflow and diminishes the tendency for vocal fold vibration (eg, slows the vocal folds down). So, in offset, there are competing forces simultaneously increasing and decreasing F_O, creating a relatively stable F_O prior to the voiceless consonants. For the onset, there is an additional increase in F_O. Because of the narrowing of the airway due to adducting vocal folds; higher airflows occur, facilitating a frequency increase in vocal fold vibration. So, in onset, there is an overall additive increase in F_O. Stepp et al[13] found that in their study, those with vocal hyperfunction may not have showed predicted frequency increases in offset due to age and the notion that generalized increase in muscle activation of the laryngeal musculature (intrinsic and extrinsic) may have yielded unpredicted results. However, in healthy young adults, with no history or vocal pathology, the predicted results should hold.

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RFF has been successfully employed to determine changes in hyperfunction.[14] Consequently, it presents itself as a viable measure to track changes in muscular activation during emotional states. In states of hyperfunction, the last 10 cycles of offset would remain relatively flat, or slightly increased in states of hyperfunction given the effect of increased tension on F_O.[14] In states of relaxation as might be observed in positive affect, the last 10 cycles of offset would potentially decrease because muscular tension would not adequately balance out the reducing F_O that result from decreasing airflow due to the abducting vocal folds. For states of hyperfunction in negative or aversive states, the first 10 cycles of onset might produce an increase in F_O compared to neutral conditions given the additive value to F_O of increased tension and aerodynamic forces due to the adducting vocal folds. Conversely, for states of relative relaxation assumed to be observed in positive conditions, the first 10 cycles of onset might be flatter because there is a decrease in tension and therefore the additive effect on F_O would be less. The fact that RFF may indicate both muscular tension and aerodynamic forces makes this measure worthwhile as there is evidence that emotional states not only affect muscular effort but also aerodynamic activity in an individual.[16]

The purpose of this study is to determine if RFF successfully tracks changes in emotional states for both positive and negative emotions. Based on previous research,[1–5] negative emotional states produce increased muscular activation in the larynx. Thus, it stands to reason that in negative emotional states RFF will show F_O increases in the last 10 cycles of offset compared to neutral and positive conditions and less F_O increase in the first 10 cycles of onset compared to neutral and positive conditions. Based on past research, evidence for laryngeal activation during positive emotional states has been inconclusive.[2,3] However, if the expected positive emotional states are accompanied by an overall reduction in muscular tension,[3] then the last 10 cycles of offset will show reducing F_O and the first 10 cycles of onset will show limited F_O increase.

METHODS

Participants

Twenty-six vocally healthy females ages 20–42 years (mean [M] 23 years, standard deviation [SD] 4.2 years) were all consenting undergraduates at Northern Illinois University participating in research for course credit. Given the gender make-up of students in the communication sciences and disorders, only females were included in this experiment because no males were available to volunteer to participate. Vocal health was determined through self-report, a voice handicap index score under 21 (average participant score 10.5),[17] and an informal auditory perceptual screen performed by the first author who is a certified speech language pathologist specializing in voice.

Stimuli

Emotion induction stimuli included pictures from the International Affective Picture System.[18] Participants viewed three blocks of 24 pictures for a total of 72 stimuli presentations. Each block contained three emotional conditions; aversive (negative), neutral, and positive. There were eight pictures per condition per block. To reduce the possibility of habituation, stimuli were quasi randomized to avoid no more than three successive pictures of the same conditions.

Instrumentation

To capture the audio signal for future processing, a microphone (ISOMAX, Countryman, Menlo Park, CA) was placed 10 cm from the participant's mouth at a 45° angle. A Roland R-26 Portable Recorder (Roland Corporation, Los Angeles, CA) captured and digitized the microphone signal at 96 kHz with 24-bit depth. Audio files were saved as .wav files and analyzed using PRAAT (6.0.37) software.

Measures and processing

RFF offset and onset were the dependent variables of interest. PRAAT[19] was used to calculate timing of pressure waves for both RFF offset and onset based on the vocalization /afa/. RFF offset contained the last 10 periodic cycles of voicing offset from /a/ to /f/. RFF onset contained the first 10 periodic cycles of voicing onset from /f/ to /a/. Cycle times were uploaded to Excel (Microsoft, Seattle, WA) and the cycle's period in milliseconds was calculated. Then, the reciprocal of the period was calculated to produce the frequency in Hz. The frequency for each cycle was converted to semitones as is typical in this measure using the calculation:

$$39.86 \times \log_{10} \frac{\mathrm{Fo}(cycel\ of\ interest)}{\mathrm{Fo}\ (reference\ cycle)}$$

where the reference cycle for offset was the 10th cycle back from the offset and the reference for the onset cycle was the 10th cycle following the onset. The difference between the 10th and first cycle from the end on the /a/ to /f/ transition was calculated for the offset. The difference between the first and 10th cycle from the beginning on the /f/ to /a/ transition was calculated for the offset.

Procedures

After participants consented and completed the voice handicap index and a brief intake from, they were seated in a comfortable chair approximately 4 feet from a 24-inch monitor (ASUS VS248H-P 24, Taiwan). Participants viewed a small fixation point lasting 500 ms to facilitate visual focus. Following this fixation point, a picture appeared on the screen for 1000 ms. As soon as the picture appeared, participants produced the VC-V production /afa/. Participants were instructed to produce /afa/

with no prosodic stress and without glottalizations. Following the completion of the picture viewing, participants verified their current emotion via self-report on a 9-point Likert-type scale and then next trial began. There were no discrepancies in self-report and picture viewing. The entire experiment lasted 20 minutes.

Analysis

The design is a within participant repeated measures design with all participants exposed to all stimuli. A number of analyses took place. Analysis for this measure is no standardized and so two approaches were made. The first approach was an analysis of the the offset and the onset to capture differences in the final degree of change from the baseline among emotional conditions. For the offset, a single factor analysis of variance (ANOVA) (aversive, neutral, and positive) compared the difference for positive, neutral, and aversive conditions in the difference between the 10th and 1st cycle. Similarly, for the onset, a single factor ANOVA (aversive, neutral, and positive) compared the difference for positive, neutral, and aversive conditions between the 1st and the 10th cycle.

The second approach was an analysis of the RFF curve as a whole to capture overall pattern changes among emotional conditions. For this approach a one-way ANOVA was conducted to assess if there were overall differences in the complete offset lines for all 10 data points as a whole. Likewise, a one-way ANOVA was conducted to assess if there were overall differences in the complete onset lines for all 10 data points as a whole.

Finally, based on previous research[1–3] it is common for individual separation of emotional states to be meaningful, but share activation similarities with each other which do not fit into established statistical models. Because of this, individual analysis of aversive, neutral, and positive conditions for offset and onset using Student's t tests will provide insight into the contributions of individual emotion states.

RESULTS

Offset

Figure 1 shows the offset, the last 10 periodic cycles as the vocal folds begin to adduct to produce the voiceless consonant /f/ for aversive, neutral, and positive conditions. A single factor ANOVA was conducted to assess if there were differences in the last cycle of the Offset of /afa/ (cycle 10) when participants were viewing aversive, neutral, and positive pictures. There was no significant differences when comparing the three groups together, $F(2, 69) = 0.95$, $P = 0.384$, $f = 0.164$. However, observation of the data suggest that there were differences between conditions with the positive condition presenting lower 10th-cycle Offsets ($M = 0.029$, $SD = 0.096$ semitones) than aversive 10th-cycleOffsets ($M = 0.288$, $SD = 0.053$ semitones). Separate emotional condition comparisons revealed a significant difference between the positive and aversive conditions $t(17) = -1.73$, $P = 0.048$ and the neutral (M = -0.005, $SD = 0.048$ semitones) and aversive conditions $t(18) = 2.10$, $P = 0.009$; but not between the positive and neutral conditions $t(10) = 2.11$, $P = 0.783$.

In observing the data as a whole, there were differences throughout the last 10 cycles of the Offset. A one-way ANOVA was conducted to assess if there were overall differences in the complete Offset lines for all 10 data points as a whole. There was a significant differences in the Offset line when comparing the three groups together, $F(2, 27) = 3.99$, $P = 0.032$, $f = 0.52$. Where the aversive offset was generally higher overall ($M = 0.288$, $SD = 0.053$ semitones) than positive Offset ($M = 0.027$, $SD = 0.095$ semitones) or neutral Offset ($M = -0.007$, $SD = 0.048$ semitones).

Onset

Figure 2 shows the Onset, the first 10 periodic cycles as the vocal folds turn on to produce the vowel /a/ for aversive, neutral, and positive conditions. A single factor

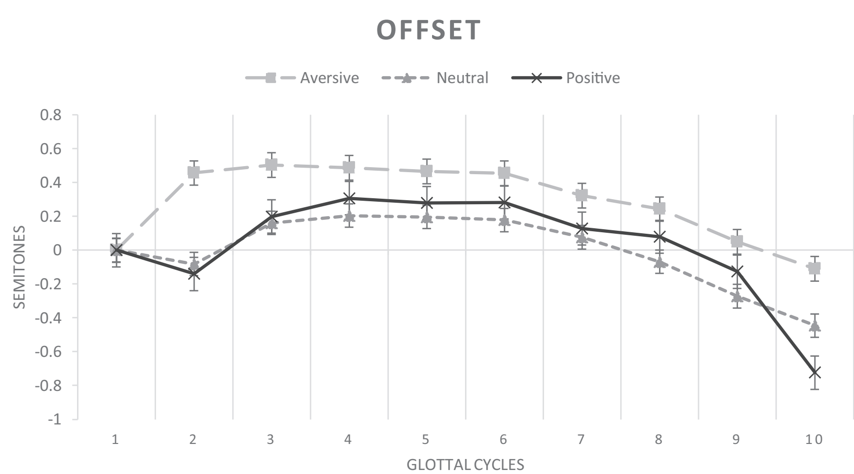

FIGURE 1. The last 10 periodic cycles (with cycle 1 as the reference) as the vocal folds are abducting to produce the voiceless consonant /f/ after /a/ for aversive, neutral, and positive conditions. Error bars represent the standard error.

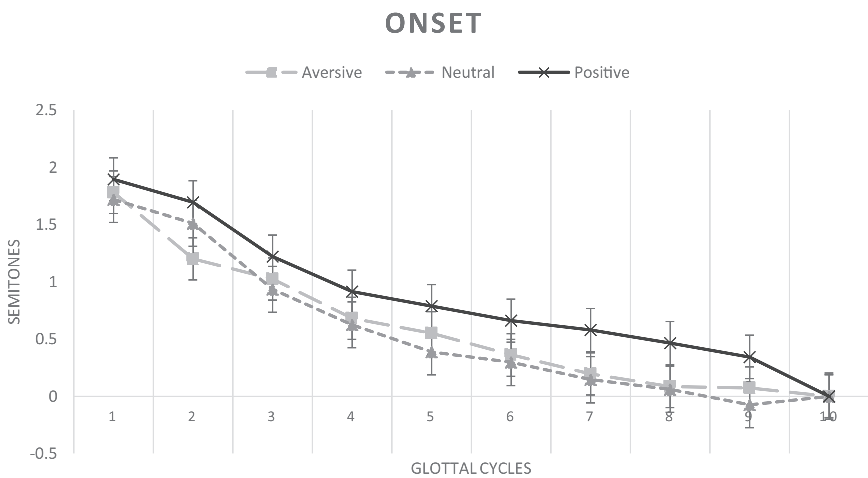

FIGURE 2. The first 10 periodic cycles (with cycle 10 as the reference) as the vocal folds are adducting to produce the vowel /a/ after /f/ for aversive, neutral, and positive conditions. Error bars represent the standard error.

ANOVA was conducted to assess if there were differences in the first cycle of the Onset of /afa/ (cycle 1) when participants were viewing aversive, neutral, and positive pictures. There was no significant differences when comparing the three groups together, $F(2, 69) = 0.05$, $P = 0.950$, $f = 0.036$. There were no significant post hoc comparisons between individual conditions.

A single factor ANOVA was conducted to assess if there were overall differences in the Onset lines for all 10 data points as a whole. There were no significant overall differences in the onset $F(2, 27) = 0.716$, $P = 0.498$ nor were there significant post hoc comparisons between individual conditions.

DISCUSSION

The purpose of this study was to determine if RFF successfully tracks changes in emotional states for both aversive/negative and positive emotions. The results showed that particularly for offset, aversive emotional states maintained a relatively flat RFF. This flat RFF has been proposed to be a balance of (a) CT stiffening (increasing F_O) and (b) reduced airflow (decreasing F_O).[13–16] The aversive offset differs compared to positive and neutral emotional states, which showed a reduction in final F_O indicative of reduced CT stiffening or reduced airflow. This finding was unexpected given that past research demonstrated increases in muscular activity in negative states as inferred by electroglottographic closed quotient.[2,3] However, in RFF, the muscular activation is postulated to be in the CT muscle, which may or may not be the same muscular activation employed in increased closed quotient.[20] So, this finding could indicate that there may be a number of different muscular responses in negative states. This has not been corroborated in other research,[5] so additional studies are needed to clarify this assumption.

The increased drop-off of F_O for positive and neutral emotional states suggests that in these conditions there is *less* CT activity used for fine vocal motor control allowing the reduced airflow to cause the F_O to lower.[16] These findings support the notion that the absence of negative affect might also influence voicing by presenting a relatively relaxed muscular phonatory posture in the CT muscle. It also suggests that aversive emotional states are accompanied by a relatively increased musculature of the laryngeal mechanism compared to positive and neutral emotional states. However, in this phonatory measure, RFF, negative emotional states mirrored a more typical phonatory response and therefore these suppositions require additional investigations for confirmation.

Findings from the RFF Onset yielded no significant differentiation between conditions, despite an increase in the overall average curve for positive conditions. The fact that no conditions showed a characteristic difference may be due to a number of factors. The cumulative increase in onset F_O is a result of the combined contribution of muscular and aerodynamic factors. If there was a contribution of only one of these factors for an emotional condition, for example muscular activation of the CT in aversive states, this difference may not have been readily observable in the output of onset F_O. In addition, if the contribution was small, as is typical in this line of research, the power to detect differences may have been too small. The number of trials per participant and the number of participants might not have been enough. Another reason could be due to habituation effects of the emotional stimuli. Emotion state was induced via picture viewing and could have dissipated during the additional task of saying the syllable /afa/. So, initial the salience of the emotional states could have been greater in the first part of the utterance but have dissolved during the last part of the utterance, which in turn could have affected the measure.

One of the reasons for choosing RFF as a measure to assess vocal responses to emotion is that this measure relies on the muscular *and* aerodynamic forces in the larynx[16]; thus, providing a potential mechanism to assess the relative contribution of muscle versus aerodynamic activation. Past studies have noted that respiratory drive may change in aversive conditions,[2] which may contribute to a compensatory muscular activation in the larynx in aversive conditions. Because emotions have a direct influence on the respiratory system,[21] effects of emotion on the laryngeal musculature (via muscle activation) may, in fact, be indirect. Data from this study does begin to separate these two competing influences during Pffset, where the muscular forces of the CT are balanced by aerodynamic forces. There appears to be a reduction in RFF during positive and neutral emotions, suggesting that in these states, it is the muscular forces that are lifted and the aerodynamic forces predominate. Conversely, in aversive emotions, muscular activation appears to maintain RFF. These findings suggest that during fine motor control the larynx may be directly influenced by emotional states.

Contrary to predictions, there appears to be no separation of neutral and positive states. This weakens the speculation that positive emotional states are accompanied by relative increased relaxation of the laryngeal musculature because neutral states are also accompanied by the same effect. There could be two reasons for this lack of separation between positive and neutral emotions observed in this and other similar research. First, emotional activation only affects the laryngeal musculature in aversive emotional states. This notion is supported by the negativity bias theory[22] that states that if positive and negative stimuli are of equal potency, negative stimuli is more salient and therefore individuals will respond more to them. Second, vocalization is inherently positive and therefore there is a positive effect even in neutral states. This notion is compelling given that there is theoretical evidence that our underlying audio-vocal communication system serves appetitive functions in communication.[23] However, the data does not corroborate this notion, given that in other studies, individuals self-report a difference between positive and neutral states.[1–3] However, more specific research is needed to parse out the subtle difference between positive and neutral states employing measures that may be more sensitive to positive emotions.

Future directions

RFF proves to be a promising measure to capture changes in laryngeal muscle activation during fine motor control in voicing. To further substantiate its potential to track vocal changes in emotional states, future studies should employ this measure with individuals who present with temperamental differences (eg, those responding more to negative stimuli than positive stimuli) and in different clinic populations where temperament may play a role in the development of a voice problem.[7] Future studies should also employ a combination of other aerodynamic measures to continue to pars out relative contributions of respiration and laryngeal muscular activation during emotional states. In addition, future studies would benefit from employing electromyography to confirm these results.

Limitations of the study

Limitations of this study include the use of the VC-V, /afa/, which may not necessarily reflect everyday conversation. However, the measure still remains promising to employ in the research laboratory to measure the effects of emotion on laryngeal musculature. Another limitation to the study is that the emotional induction stimuli (viewing pictures) and the way they were presented (in relatively rapid sequence) may not reflect what is typically observed in everyday life. It may be that emotional states in real life are developed over a longer time period and the recovery of such emotions may take longer, leading to different laryngeal responses. A final limitation to the study is that, for practical reasons, it was only performed on women. It remains to be seen whether this effect is observed in men.

CONCLUSIONS

RFF was employed in an emotional induction paradigm and successfully differentiates aversive emotional states from positive and neutral emotional states. This differentiation was observed during RFF offset with positive and neutral emotional states having a reduction in RFF offset, which may reflect reduced CT during offset.

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