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Vibratory onset and offset times in children: A laryngeal imaging study

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ABSTRACT

Objectives: The aim of the study was to evaluate the differences in vibratory onset and offset times across age (adult males, adult females, and children) and waveform types (total glottal area waveform, left glottal area waveform, and right glottal area waveform) using high-speed videoendoscopy.

Methods: In this prospective study, vibratory onset and offset times were evaluated in a total of 86 participants. Forty-three children (23 girls, 18 boys) between 5 and 11 years and 43 gender matched vocally normal young adults (23 females and 18 males) in the age range (21–45 years) were recruited. Vibratory onset and offset times were calculated in milliseconds from the total, left, and right Glottal Area Waveform (GAW). A two-factor analysis of variance was used to compare the means among the subject groups (children, adult male, and adult female) and waveform type (total GAW, left GAW, right GAW) for onset and offset variables. Post hoc analyses were performed using the Fishers Least Significant Different test with Bonferroni correction for multiple comparisons.

Results: Children exhibited significantly shorter vibratory onset and offset times compared to adult males and females. Differences in vibratory onset and offset times were not statistically significant between adult males and females. Across all waveform types (i.e. total GAW, left GAW, and right GAW), no statistical significance was observed among the subject groups.

Conclusion: This is the first study reporting vibratory onset and offset times in the pediatric population. The study findings lay the foundation for the development of a large age- and gender-based database of the pediatric population to aid the study of the effects of maturation of vocal fold vibration in adulthood. The findings from this study may also provide the basis for evaluating the impact of numerous lesions on tissue pliability, and thereby has potential utility for the clinical differentiation of various lesions.

1. Introduction

Vocal fold vibration is a complex interaction between subglottal pressure and vocal fold tissue properties. The complex interaction between the these two factors can be evaluated using vibratory onset and offset times. Vibratory onset time is defined as the time interval between the first instance of vibratory motion to the beginning of the steady-state phonation [1,2]. Similarly, vibratory offset time is defined as the time interval between the first instance of departure from the steady-state phonation to complete cessation of vibratory motion [2]. Based on the definitions of vibratory onset and offset times, it is evident that these are transitory phenomena, requiring high temporal resolution to capture them. High-speed videoendoscopy [1–5] offers the necessary temporal resolution to capture the transient onset and offset phenomena.

The vibratory onset and offset time can be altered by changes in laryngeal geometry or by vocal fold pathologies [1,5–7]. Vibratory onset and offset can be affected by unilateral pathologies affecting the vocal folds such as vocal fold cysts, polyp, laryngeal papilloma, unilateral vocal fold paresis/paralysis. Functional voice disorders/muscle tension dysphonia often presents with asymmetries between the right and the left vocal fold onset times. The target pitch, loudness, and the type of phonation (e.g. hard glottal attack, breathy voice, and balanced voice) can also influence the vibratory onset and offset times. In turn, such changes in the vibratory onset and offset time can affect the steady-state vocal fold vibrations and overall voice quality. Evaluation of vibratory onset and offset times could potentially provide insights into the tissue pliability [1,7] and integrity of the neuromuscular coordination of the vocal system [8,9]. In recent years, much research has been conducted on

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differentiating vocal function between children and adults using analysis of sustained phonation. Differences in vocal function between children and adults have been investigated in the literature using acoustic [10–19], aerodynamic [20–24], electroglottographic [25], and laryngeal imaging modalities [26–30]. However, literature on direct measures of vibratory onset and offset times from techniques of laryngeal imaging is scant in adults [2,5–8,31–36] and virtually nonexistent in the pediatric population.

To date, studies investigating vibratory onset [2,6,7,31,32] and offset times [2,6] in vocally normal adults are on small numbers of participants and have used different types of waveforms, resulting in variable findings. Measurements that quantify vibratory onset and offset times have used two types of waveforms: the total glottal area waveform [2,36] and individual vocal fold trajectories obtained from various points along the length of the vocal fold [5–7,31,32,34–36]. While the glottal area waveform and the vocal fold trajectories from points along the vocal fold length provide valuable information regarding the change in the glottal area and tissue motion of the selected points, they do not offer insights into the separate behavior of the left and the right vocal folds in their entirety. The intent of analyzing left and right vocal fold motion separately is to evaluate not only the tissue pliability of the entire vocal fold but also the symmetry in the onset and offset gestures between the left and the right vocal folds in the developing larynx. In addition to the known differences in the length of the right and the left recurrent laryngeal nerves, there are differences in the size [37], myelination, and dendritic and axonal endings in the pediatric vagus nerve compared to the adults [38]. How these differences affect the vibratory onset and offset times between the left and the right glottal area waveforms has not been systematically investigated in either children or adults.

It is well accepted that there are structural differences in the laryngeal framework between children and adults; however, there are fine microstructural differences in the vocal fold layers between children and adults. Children have smaller laryngeal cartilages [39–42] and vocal fold length [42–44]. Perpubertal children have an underdeveloped vocal fold ligament and lamina propria that is hypocellular and not fully developed until 13 years of age [43,45,46]. There are also differences in the extracellular matrix in terms of the fiber and protein compositions [47], suggesting that the vocal folds in children are more elastic compared to those of adults. These findings suggest that there are differences in the width and the stiffness of the body (muscle) and the cover (epithelium and the lamina propria) [48] in children, thereby altering the geometry and the depth of the vibration of the body and the cover involved in onset and offset. The influence of smaller laryngeal size on the vibratory mechanism of onset and offset has been examined using some models, but not using in vivo studies. Lumped mass models and two-layer body-cover continuum model [49] have shown that the vocal fold vibrations at onset and offset vary depending on the stiffness of the body and the cover [49,50], subglottal pressure, and glottal area [51–53]. For smaller larynges as in children, findings from lumped mass models of the vocal folds reveal that the vocal fold oscillations and the glottal airflow are reduced due to the smaller size [52]. Based on the above stipulations, we expect children to have shorter vibratory onset and offset times compared to adults. Since in vivo studies are benchmarks for quantifying vibratory onset and offset, we hope to provide empirical data to validate the theoretical models by experimentally evaluating these phenomena. Consequently, our study could help develop theories of vocal fold vibratory motion in children. The aim of the study is to evaluate the differences in vibratory onset and offset between typically developing children and adults across three different waveform types: total, left, and right glottal area waveform.

2. Methods

2.1. Participants

Eighty-six participants were recruited for this study at the Vocal Physiology and Imaging Laboratory, Indiana University, after signing of appropriate Institutional Review Board approved consent and/assent forms. A total of 43 children (girls = 25, boys = 18) aged 5–11 years (mean = 8.2 years) without any voice disorder were recruited. Gender-matched young adults (21–45 years, mean = 23.6 years) without any voice disorders were recruited for the control group. Children and adults were recruited in the study if their overall voice quality was perceptually rated as normal (Overall Grade = 0) on the GRBAS [48] scale and if they had negative histories of vocal fold pathology. Children undergoing puberty as evident from case history were excluded from the study. Adults with a history of smoking were excluded from the study.

2.2. Data collection

All recordings were performed in a double-walled, sound-proof room. High-speed videoendoscopic recordings were captured at 4000 frames per second with the spatial resolution of 512 × 256 pixels (PENTAX digital Model 9710, Montvale, New Jersey) to obtain vibratory onset and offset. The recording duration of 4 s was appropriate to capture the short rapid events of vibratory onset and offset. Simultaneous acoustic recordings were captured with high-speed videoendoscopic recordings at a sampling rate of 50 kHz with a mouth-to-microphone distance of 5 inches. A minimum of three consecutive repetitions of/hi/were recorded. Participants were instructed to produce repeated production of/hi.hi.hi/at self-selected conversational pitch and loudness. Since the consonant/h/is a voiceless glottal fricative, the combination of a/hi/was selected because it is produced with a fairly open vocal tract without supraglottal constrictions. The use of/h/also prevents the occurrence of hard glottal attacks [36], which is critical for obtaining the true vibratory onset and offset time of the vocal folds.

2.3. Data segmentation and analysis

When determining the onset and termination of phonation, the middle syllable production of/hi/was segmented from the high-speed video recordings for all participants in order to elimininate any abrupt vibratory events. The start frame of the segment was selected when the arytenoids were in a fully abducted position prior to the first instance of adductory motion, and the end frame of the segment was selected when the arytenoids were in the fully abducted position immediately after complete cessation of the vocal fold vibratory motion.

Glottal area waveforms (GAW) representing the vibratory onset and offset behavior of the vocal folds were extracted from the high-speed video using the Glottal Analysis tools [54] developed at the Department of Phoniatrics and Pediatric Audiology, Erlangen, Germany. Vibratory onset and offset times were obtained for the total, left, and right glottal area waveform for all participants (Fig. 1). The total glottal area waveform represents the area of the entire glottis over time. The left glottal area waveform characterizes the area of the left vocal fold with respect to the central glottal axis over time, whereas the right glottal area waveform represents the area of the right vocal fold from the central glottal axis over time. The amplitudes of all the glottal area waveforms were normalized from 0 to 1, where 0 represents complete vocal fold closure and 1 represents maximum glottal opening during a glottal cycle.

The vibratory onset time (milliseconds) was calculated as the time interval between the first visually identifiable vibratory