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Pediatric high speed digital imaging of vocal fold vibration: A normative pilot study of glottal closure and phase closure characteristics☆

Rita R. Patel [a,*], Angela Dixon [a], AnnaMary Richmond [a], Kevin D. Donohue [b]

[a] Department of Rehabilitation Sciences, Division of Communication Sciences & Disorders, University of Kentucky, Lexington, USA
[b] Department of Electrical & Computer Engineering, University of Kentucky, Lexington, USA

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ABSTRACT

Objective: The aim of the study is to characterize normal vibratory patterns of both glottal closure and phase closure in the pediatric population with the use of high speed digital imaging.
Methods: For this prospective study a total of 56 pre-pubertal children, 5–11 years (boys = 28, girls = 28) and 56 adults, 21–45 years (males = 28, females = 28) without known voice problems were examined with the use of a new technology of high speed digital imaging. Recordings were captured at 4000 frames per second for duration of 4.094 s at participants' typical phonation. With semi-automated software, montage analysis of glottal cycles was performed. Three trained experienced raters, rated features of glottal configuration and phase closure from glottal cycle montages.
Results: Posterior glottal gap was the predominant glottal closure configuration in children (girls = 85%, boys = 68%) with normal voice. Other glottal configurations observed were: anterior gap (girls = 3.6%, boys = 0%), complete closure (girls = 7%, boys = 10%) and hour glass (girls = 0%, boys = 11%). Adults with normal voice also demonstrated predominantly higher percentage of posterior glottal gap configuration (females = 75% male = 54%) compared to the configurations of anterior gap (females = 0% male = 7%), complete closure (females = 2% male = 39%), hour glass (females = 3.6% male = 3.6%). A predominantly open phase (51–70% of the glottal cycle) was observed in 86% girls and 71% boys. Compared to children, adult females showed a predominantly balance phased closure 46%, followed by open phase (39%) and predominantly closed phase (14%). Adult males showed a predominantly closed phase (43%), followed by predominantly open phase (39%), followed by a balanced phase (18%).
Conclusions: This is a first study investigating characteristics of normal vibratory motion in children with high speed digital imaging. Glottal configuration and phase closure for children with normal voices are distinctly different compared to adults. The results suggest that posterior glottal gap and a predominantly open phase of the glottal cycle should be considered as normal glottal configuration in children during modal pitch and loudness. This study provides preliminary information on the vibratory characteristics of children with normal voice. The data presented here may provide the bases for differentiating normal vibratory characteristics from the disordered in the pediatric population.
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1. Introduction

Accurate imaging procedures are an essential tool for clinical management of vocal fold pathologies in the pediatric population [1]. It has been documented that stroboscopy with distal chip tip flexible endoscopy [1] and with rigid endoscopy are feasible [2,3] and particularly valuable in pediatric patients with a history of prolonged dysphonia, for whom initial treatment has failed. Superior accuracy in laryngeal imaging has been demonstrated in adults with high speed imaging compared to stroboscopy [4,5]. However, similar high speed imaging studies have not been completed in the pediatric population. Moreover, the diagnostic value of pediatric videostroboscopy and its abilities to differentiate between different phonatory mechanism and voice pathologies are limited as there is insufficient information in the literature on what constitutes normal vibratory motion in the pediatric population.

Although stroboscopy is the preferred [1] assessment tool for clinically evaluating vibratory properties of the vocal fold; it appears to be limited for studying vibration patterns of normal and

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* Corresponding author at: University of Kentucky, 900 South Limestone, 120 D Charles T. Wethington Building Lexington, KY 40536-0200, USA.
Tel.: +1 859 218 0471; fax: +1 859 323 8957.
E-mail address: rita.patel@uky.edu (R.R. Patel).

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disordered pediatric phonation, because of its limited temporal resolution and requirement of fairly regular vibratory patterns for at least 3–4 s before the strobe light can track phonation. Due to variability in attention span and cooperation in children, it is often difficult to obtain pediatric phonation samples of greater than 2–3 s [2], often resulting in non-interpretable stroboscopic findings. With maximum frame rate of 30 frames per second, stroboscopy is often insufficient for examining voice disorders in children, who have a fundamental frequency of greater than 255 Hz, due to lack of an adequate amount of frames per second that can be captured from children [6,7].

High speed digital imaging (HSDI), unlike stroboscopy, can record *actual* cycle-to-cycle variations in vibratory motion [4] with superior temporal resolution of up to 8000 frames per second. In a two second segment, for phonation of 250 Hz, HSDI recorded at 4000 frames per second can record approximately 130 times more vibrations compared to digital stroboscopy. A comparison of vibratory motion observed on stroboscopy and HSDI is illustrated in Fig. 1. In this example, the HSDI at 4000 fps, for a pitch of 250 Hz results in capturing 16 frames per glottal cycle. For stroboscopy operating at 30 frames per second only 0.12 frames per glottal cycle are captured. The first flash of stroboscopic light would be triggered after 8.33 glottal cycles or 133.28 frames. Hence, with stroboscopy considerable information is lost regarding successive glottal cycles. The detailed temporal resolution afforded by HSDI appears to be ideal for comprehensive clinical appraisal of vibratory motion children's voice quality that is characterized by higher habitual fundamental frequency and short phonation duration. To our knowledge the present study is the first to undertake direct study of vocal fold vibrations with HSDI in children.

Identification of glottal closure configuration and phase closure, through direct visualization of vibratory patterns is fundamental to appropriate diagnosis and treatment of vocal pathology. Vocal fold closure configuration during normal phonation has been shown to change with age in adults due to the anatomical changes in the larynx as part of the aging process, with young women predominantly demonstrating a posterior gap and incomplete closure configuration, whereas the elderly women demonstrated higher incidence of anterior gap and spindle shaped glottal configuration [8]. However, experimental investigations of vocal fold vibratory changes associated with growth and development in children are lacking, despite the recognition that the pediatric larynx is not merely a miniature version of the adult larynx. It has been well documented that children have voices that are different from adults. Empirical evidence thus far from measurement of aerodynamic characteristics [9–12], vocal fold histology [13–18], laryngeal framework [14,16], acoustic [19–22], and electroglottographic [23] assessments of vocal function, have all demonstrated differences between the pediatric and adult voices. The acoustic, aerodynamic, and electroglottographic changes in voice are thought to be due to the anatomical age-related changes in the size of the larynx and the layered structures of the vocal folds.

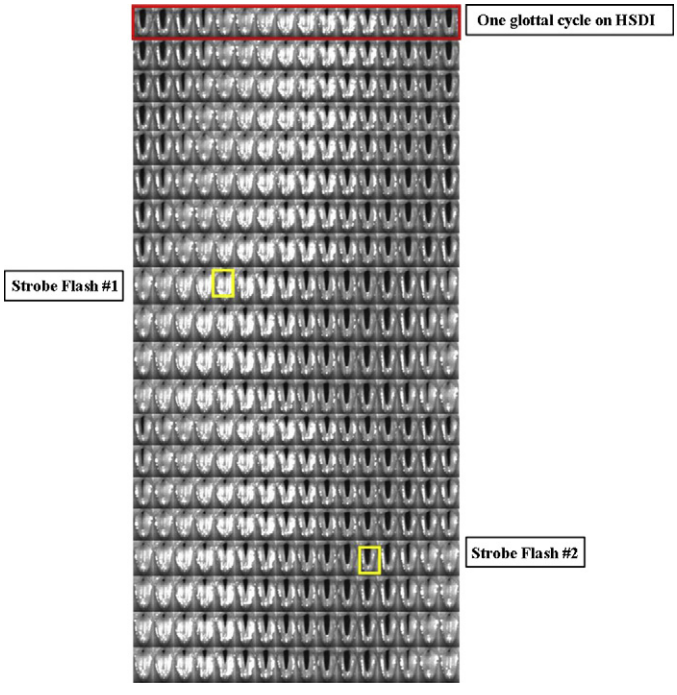

Fig. 1. Comparison of glottal cycles obtained from high speed digital imaging (HSDI) and stroboscopy. The glottal cycle montage is generated from a 9 year old female during production of sustained/i/at normal pitch and loudness with a fundamental frequency of 250 Hz. The red box represents one glottal cycle. On HSDI 16 frames (red box) can be captured for one cycle, however the first stroboscopy flash light (yellow box) is triggered only after ~8 glottal cycles, indicating missing information from each subsequent 8 glottal cycles or 133.28 frames.

Data on vocal fold motion from adults [24] is valuable, but cannot be used for direct interpretation of pediatric phonation as laryngeal anatomy and the vocal fold layered structures in the pediatric population differ considerably when compared to adults. Children have shorter membranous portion of the vocal folds [14,25] and less differentiated vocal ligament with thicker mucosa [9,11]. How these structural differences of the pediatric glottis translate into unique vibratory motion characteristics is not known. The goal of the present study is to evaluate if age and gender related differences in glottal closure configuration and phase closure exists, in typically developing children (5–11 years) compared to young adults (21–45 years) for modal (typical) phonation with the use of HSDI.

2. Methods

2.1. Participants

A total of 131 participants; 75 children, age range (5–11 years) and 56 adults (21–45 years) were recruited through the University of Kentucky Vocal Physiology and Imaging Laboratory via IRB approved advertisements and fliers placed around the University of Kentucky campus and the University of Kentucky Children's Hospital. Data from 11 children could not be obtained due to heightened gag reflex. All participants or their proxies completed appropriate IRB approved informed consent and assent forms. Participants were included in the study if they met the following criterion: had negative histories of vocal pathology, were not professional voice users, perceptually judged to have normal voice by a certified speech language pathologist specializing in voice disorders. Participants going through puberty as identified via case history and parental interview were excluded. Selection criteria for adult participants were similar to those of pediatric group, except that the adult participants had a negative history of smoking.

2.2. Data collection/instrumentation

High speed recordings were performed with KayPentax, model 9710 at 4000 frames per second for a maximum duration of 4.094 s (limited by the duration of the available instrument) with spatial resolution of 512 × 256 pixels. Simultaneous acoustic signal was sampled at 50 kHz. Acoustic recording was used to confirm the presence of steady state phonation and participants' task performance of typical pitch and loudness. All participants performed three trials of typical phonation before recording with HSDI. The participants were asked to sustain typical phonation on the vowel/i/that was ±10 Hz of their speaking fundamental