THE EFFECT OF AGE ON CEPSTRAL MEASURES OF PHONATION IN FEMALE SPEAKERS

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ABSTRACT

The purpose of this study was to investigate the effect of age on acoustic measures of voice production in female children and female adult speakers. Thirty-four speakers were recruited into child (6-10yrs) and adult (18-25yrs) groups. Acoustic measures of fundamental frequency (Fo) and cepstral peak prominence (CPP) were utilized to examine: (1) Does female age affect CPP in vowels and sentences? (2) Does female age affect fundamental frequency in vowels and sentences?. Participants were recorded producing the vowels /i/ and /a/, and a Consensus Auditory Perception Evaluation of Voice (CAPE-V) sentence; recordings were then analyzed with the PRAAT program. Contrary to the posed hypothesis, results indicated that in most speaking conditions CPP did not differ significantly between age groups. However, F_o was found to be significantly higher in the child group for all speaking conditions. The present study may support future endeavors of developmental CPP norms and clinical application.

TABLE OF CONTENTS

INTRODUCTION

The Larynx is a structure located in the midline of the neck, which plays a role in respiration, swallowing, and phonation. The Larynx is composed of cartilages, muscles and tissue whose structure and physiology are crucial for normal laryngeal function. The Larynx houses and protects the vocal folds, which are responsible for voiced sound production during phonation. The overall laryngeal structure changes as an individual matures from a child to an adult. These developmental transformations lead to differences in vocal function realized by age-related changes to vibratory behavior during phonation and the resulting acoustic output.

Changes in vocal function can be measured acoustically. Traditional acoustic measures of vocal function have included fundamental frequency, frequency perturbation (jitter), and amplitude perturbation (shimmer), the latter two measures representing the periodicity or regularity of vocal fold vibration. These traditional acoustic measurements have utilized software that requires detection of cycle boundaries over time in order to calculate these measures. These are referred to as time-based acoustic measures. Time-based acoustic measures are limited only to analysis of sustained vowels because in connected speech cycle, boundaries are difficult to detect due to rapid changes in the acoustic spectrum. Contemporary acoustic measures such as cepstral analyses are an alternative that can validly assess periodicity and fundamental frequency in connected speech. Cepstral measurements do not rely on detection of cycle boundaries, and instead analyze the sound spectrum through Fourier analyses. However, there has been limited research utilizing these anatomical changes. To date, information on how cepstral measures change as a function of age from childhood to adulthood is not available. The purpose of this study was to examine the affect of anatomical development of the Larynx on acoustic output. To accomplish this, cepstral/spectral measures were acquired to analyze sustained vowels in connected speech produced by young and adult female speakers.

REVIEW OF LITERATURE

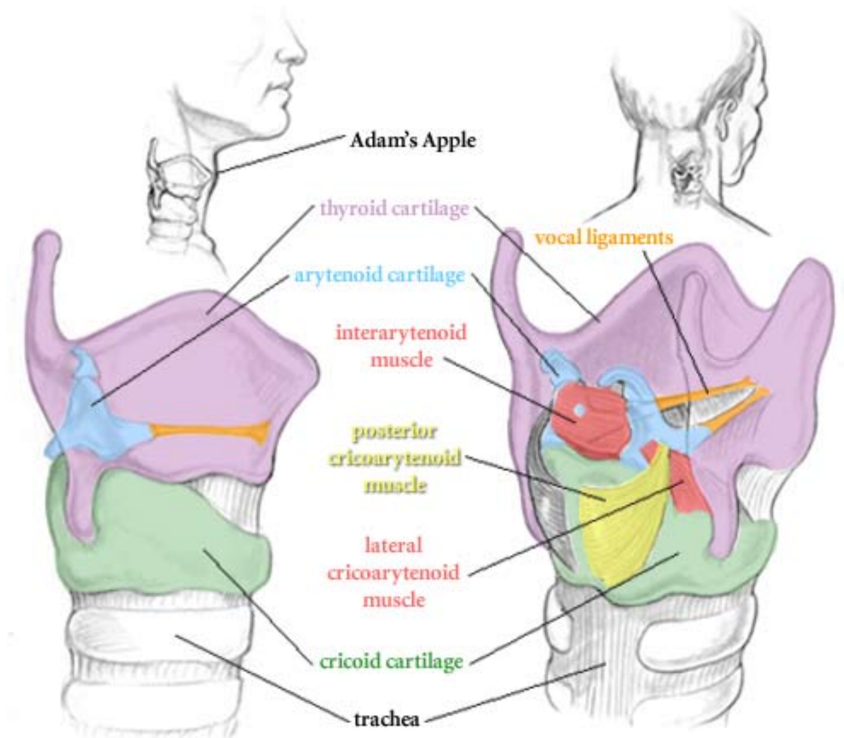
I. The Larynx

Phonation takes place within the Larynx, which is located in the anterior midline of the neck. A cartilage skeleton acts to provide a framework for the Larynx, to which muscles, ligaments, and other tissues attach. Cartilages of the Larynx include the Thyroid, Cricoid, Arytenoid, Epiglottis, Corniculate, and Cuneiform Cartilages (Figure 1). The Thyroid Cartilage is the largest in the Larynx (Drumright, King, & Seikel, 2010). It is formed by two wedge-shaped hyaline cartilage plates fused together in the middle. The fusion of the two plates in the midline of the neck forms the anterior portion of the Thyroid referred to as the laryngeal prominence and commonly known as the “Adam’s apple.” (Boone, Mcfarlane, Von Berg, & Zraick, 2014) The Thyroid Cartilage forms the anterior and lateral wall of the larynx and protects the vocal folds. The Thyroid Cartilage serves as the anterior attachment for the vocal folds, which are connected to it just below the laryngeal prominence.

The second largest cartilage in the Larynx is the Cricoid Cartilage. (Boone, Mcfarlane, Von Berg, & Zraick, 2014) The Cricoid is a ring-shaped cartilage located posterior and just inferior to the thyroid cartilage. (Boone, Mcfarlane, Von Berg, & Zraick, 2014) The anterior and lateral surfaces of the Cricoid Cartilage are thin but begin to widen as the lateral surface arches posteriorly. The posterior surface of the Cricoid is flat and rectangular. Sitting on the superior surface of the Cricoid are the Arytenoid Cartilages. (Drumright, King, & Seikel, 2010) The Arytenoid Cartilages are pyramidal shaped with two projections at their base: the vocal process and the muscular process. The vocal process serves as the posterior attachment for the vocal folds, while the muscular process serves as an attachment for intrinsic laryngeal muscles. (Boone, Mcfarlane, Von Berg, & Zraick, 2014) The Arytenoid Cartilages help to regulate the position of the vocal folds by adducting (closing) and abducting (opening).

The Epiglottis is an elastic cartilage, which sits at the superior and front portion of the Larynx. It has no role in voice production, but during swallowing it inverts to cover the opening of the Larynx. The Corniculate Cartilages are small supporting cartilages that sit on top of the Arytenoids. Along with the Cuneiform Cartilages, which lie in the Aryepiglottic Folds of the Quadrangular Membrane, they have no known function for voice or swallowing other than structural support (Drumright, King, & Seikel, 2010).

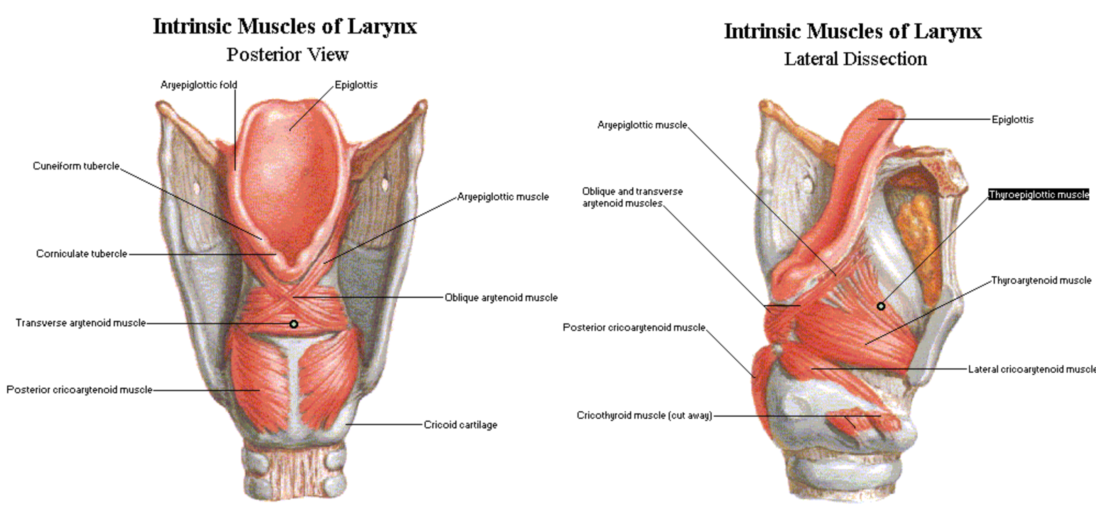
Figure 1. Cartilages of the Larynx



The Larynx has both intrinsic and extrinsic muscles that help it to function (Figures 2 & 3). (Boone, Mcfarlane, Von Berg, & Zraick, 2014) The intrinsic muscles' primary function is movement of the Arytenoid and Thyroid cartilages. Arytenoid movement can change vocal fold position (adducted or abducted). Instrinsic laryngeal muscles also influence vocal fold length and tension by moving the Thyroid Cartilage (resulting in increased length and tension) or "relaxing" the vocal folds' cover (decreasing length and tension). All intrinsic muscles have a both their points of origin and insertion within the Larynx. The intrinsic muscles include the Posterior Cricoarytenoid, Lateral Cricoarytenoid, Interarytenoid, Thyroarytenoid, and the Cricothyroid. (Drumright, King, & Seikel, 2010)

The Posterior Cricoarytenoid (PCA) is the only abductor. The PCA pivots and moves the Arytenoid laterally, which opens the glottis. (Boone, Mcfarlane, Von Berg, & Zraick, 2014) The antagonist to the PCA is the Lateral Cricoarytenoid (LCA). The LCA is a paired adductor muscle. Adduction of the LCA pivots the arytenoid medially, closing the membranous glottis. (Boone, Mcfarlane, Von Berg, & Zraick, 2014) The Interarytenoids are unique in that one division of this muscle is the only unpaired intrinsic laryngeal muscle. They are composed of the transverse and oblique bodies. (Boone, Mcfarlane, Von Berg, & Zraick, 2014) The transverse body, which is one unpaired sheet of muscle running horizontally from one Arytenoid to the other, draws the Arytenoid Cartilages together, adducting the vocal folds. (Drumright, King, & Seikel, 2010) The oblique portion of the Interarytenoids pulls together the apex of the Arytenoids and further adducts the vocal folds. (Boone, Mcfarlane, Von Berg, & Zraick, 2014)

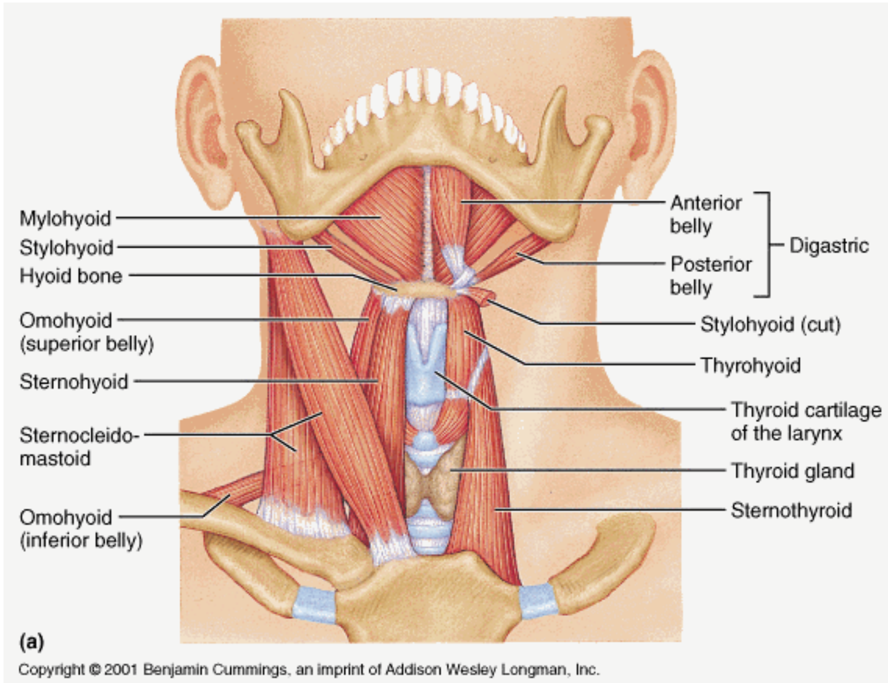
Figure 2. Instrinsic Laryngeal Muscles



The Thyroarytenoid Muscle composes the bulk of the vocal folds. The Thyroarytenoid is made up of the Thyrovocalis and the Thyromuscularis. The Thyrovocalis can act to tense or relax the vocal fold tissue, depending on the activity of the Cricothyroid. The cricothryoid will pull the Thyroid Cartilage forward and down due to contraction of the Pars Recta and Pars Oblique portions of this muscle. This movement elongates and tenses the vocal folds. If the Cricothryoid is not active, contraction of the Thyrovocalis will shorten the overall length of the vocal fold tissue, causing the vocal fold cover to “relax” or bunch up. If the Cricothryoid actively elongates the vocal folds, the Thyrovocalis will act to further increase tension in the vocal fold tissue. The Thyromuscularis adducts the vocal folds by acting on the muscular process of the Arytenoids. (Boone, Mcfarlane, Von Berg, & Zraick, 2014)

The extrinsic muscles of the Larynx have a point of origin outside of the Larynx but a point of insertion within the Larynx (typically the hyoid bone). The extrinsic muscles’ primary function is gross movement of the Larynx in the vertical dimension. The extrinsic muscles include the Laryngeal Elevators and Laryngeal Depressors. The Laryngeal elevators include the Geniohyoid, Mylohyoid, Digastric muscles, and Stylohoid. The Laryngeal depressors include the Omohyoid, Sternohyoid, Sternothyroid, and Thyrohyoid. (Boone, Mcfarlane, Von Berg, & Zraick, 2014)

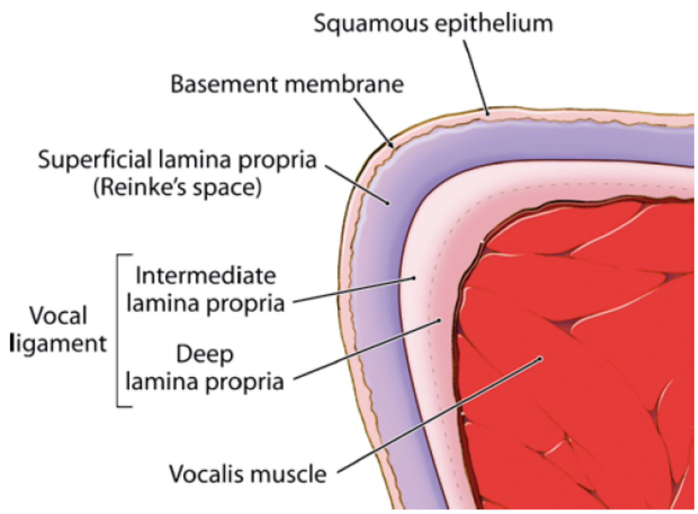
Figure 3. Extrinsic Laryngeal Muscles



The adult vocal folds are composed of five layers of tissue each with varying protein compositions. The layers of the vocal folds from most superficial inward are the Epithelium, Superficial Layer of Lamina Propria (SLLP), Intermediate Layer of Lamina Propria (ILLP), Deep Layer of Lamina Propria (DLLP), and Thyroarytenoid Muscle (Figure 4). The Epithelium of the vocal folds is a type of Stratified Squamous Epithelium and serves as the outer cover of the vocal folds (Gerdeman, Glaze, & Stemple, 1999). The Superior Lamina Propria lies underneath the Epithelium and is comprised mostly of loosely organized proteins known as “ground substance”, along with a few cellular components. (Boone, Mcfarlane, Von Berg, & Zraick, 2014)

Together the Intermediate and Deep Lamina Propria forms the Vocal Ligament. In early childhood the Vocal Ligament is not present, but develops all the way up to puberty, going through a process of differentiation from one layer of Lamina Propria at birth to three layers of Lamina Propria, including the ligament, after puberty. These layers contain an abundance of elastin and collagen fibers, with greater concentrations of elastin in the ILLP but greater concentrations of collagen in the DLLP. This results in the vocal fold becoming stiffer as you progress inward toward the Vocalis Muscle. The degree of stiffness in the Vocal Ligament can impact how the vocal folds vibrate. (Gerdeman, Glaze, & Stemple, 1999) The Vocalis Muscle provides a firm base over which the rest of the vocal fold tissue can vibrate. (Gerdeman, Glaze, & Stemple, 1999)

Figure 4. Layers of the Vocal Folds



II. Vocal Fold Development and Aging

Due to the tissue of the vocal fold changing as an infant develops from childhood to adolescence, differences in pediatric and adult vocal folds are evident both anatomically and physiologically. Anatomically it has been found that the position of the Larynx as well as the Laryngeal Cartilage size and structure differ from childhood to adulthood. (Boone, Mcfarlane, Von Berg, & Zraick, 2014) It has been found that in pre-pubertal years, ages 4-11, there is considerable general physical growth that includes the Larynx. (Sergeant & Welc, 2007)

The pediatric Larynx is positioned higher than that of the adult and reaches its final adult position after puberty. As a child grows in the pre-pubescent years the Larynx descends lower into the Pharynx. Along with the Pharyngeal Cavity the Larynx also widens leading to changes in resonance. As the positioning of the Larynx changes so does the length of the vocal folds. Newborns have vocal folds an average of 2.5-3 mm. When fully grown, male vocal folds will typically be 17-21mm and females 11-15 mm. The Hyoid Bone is also positioned lower in the child than the adult. In some cases the Thyroid Cartilage is overlapped by this lowered Hyoid. Therefore the Thyroid prominence, commonly known as the Adam's apple, will also appear around puberty. (Boone, Mcfarlane, Von Berg, & Zraick, 2014)

The composition of the pediatric versus mature vocal folds is also different, and is characterized by less membranous tissue in the vocal folds of children. (Gerdeman, Glaze, & Stemple, 1999) This ratio is partly representative of the lack of Vocal Ligament in children prior to puberty. The Vocal Ligament begins to emerge between the ages of 1 to 4 years and does not fully develop until the teen years, after puberty (Gerdeman, Glaze, & Stemple, 1999) Vocal fold mucosa (epithelium) is also thinner in infants than adults. (Boone, Mcfarlane, Von Berg, & Zraick, 2014) Overall the laryngeal cartilages in the child are less rigid and more plastic than those of the adult (Sergeant & Welch, 2007)

III. Acoustic measures of vocal fold development

A variety of means have been used to assess the acoustic characteristics of voice. Commonly used measures include jitter, shimmer and fundamental frequency. Jitter and shimmer represent the regularity, or periodicity, of vocal fold vibration. Both can be described as variability from vibratory cycle to vibratory cycle. Jitter is a measure of variability in the period (time) of vibratory cycles, while shimmer is a measure of the variability in vibratory amplitude. Fundamental frequency is a measure of the average rate of vocal fold vibration, and is measured in Hertz (Hz – cycles per second).

In a recent study of jitter, shimmer, and fundamental frequency in normal speakers, two hundred and twelve children were recorded while producing the /a/ vowel for several seconds. Results found that both a male and female fundamental frequency drop was evident, although the drop was lower in boys than in girls. No significant difference was detected in jitter and shimmer for either sex. (Garrel, Giovanni, Nazarian, Nicollas, Ouaknine, & Triglia, 2008) While this study was helpful in establishing normative data, results from other studies have not been in agreement.

Bennett (1983) also conducted research where she measured fundamental frequency in normal children. Bennett utilized a longitudinal study of 25 boys and girls over a 3-year timeline. At each meeting with the child, recordings of 12-syllable declarative sentences were taken. Her findings indicated that as the mass of the vocal fold tissue increased with age, a correlation with fundamental frequency dropping was seen. Bennett also found that prior to puberty no sexual dimorphism was present in this drop of fundamental frequency, which was in contradiction to the Garrel et al. study (Bennett, 1983).

Another study conducted by Sergeant and Welch measured acoustic characteristics of voice by using calculations of the long term average spectra (LTAS). LTAS measures spectral properties of voice (the frequency and intensity information over time), which can be used as means of inferring vocal fold vibratory behavior. The study recruited 700 children as participants. The authors' findings revealed overall spectral intensity levels change with aging. The authors also reported a positive linear relationship between increasing age and vocal range. From their study, they surmised that girls reach their full frequency range approximately two years before their male counterparts. (Sergeant & Welch, 2008) While research confirms a drop in fundamental frequency as children develop, there are still apparent discrepancies in pediatric acoustic research. Additional research is needed to mitigate such confusion and discrepancy in the literature.

IV. Cepstral/Spectral Acoustic Measures

Measures of fundamental frequency, jitter and shimmer have been found to be limited in terms of their ability to characterize voice in connected speech.

Research has shown that when measures of jitter and shimmer are applied to typical conversational speech the accuracy of the measures can be questioned. Boundaries of vocal fold cycles in waveforms of connected speech are harder to identify, which makes these measures of jitter and shimmer especially suspect for connected speech analysis as well as vowel analysis in moderately or severely disordered voices. Awan et al. (2011) reported that traditional measures used for voice analysis are limited to sustained vowels. Perturbations (rapid changes in frequency and intensity due to articulation and prosody) found in normal conversational speech are erroneously labeled when traditional measures are used. (Awan, 2011) Such a limitation has been found to lead to discrepancies in diagnosis of dysphonia where only sustained vowel measures were used.

Due to the limitations in applying valid acoustic measures only to sustained vowels in normal or mildly impaired voices, more contemporary measures have been advocated for acoustic study of vocal function. Among these are measures that utilize cepstral and spectral analyses, such as the use of the cepstral peak. The cepstrum is a spectral based measure. To derive a cepstrum, a mathematical formula known as a Fourier transform (often denoted “FFT” for “Fast Fourier Transform”) is applied to an acoustic signal. This results in a transformation of the time-varying waveform into the frequency domain, where the amplitude of each frequency component in the sound is displayed. If a second FFT is applied, it converts the signal from the frequency domain to the cepstral domain. The cepstrum enables the extraction of the fundamental frequency from the spectrum of connected speech. In addition, the amplitude of the peak in the cepstrum (cepstral peak prominence, or CPP) represents the periodicity of phonation, which is the correlate of jitter and shimmer.

Many researchers have used the cepstrum and advocate for its accuracy in both sustained vowels and conversational speech. (Awan, 2011) Recent research has found that combing cepstral measures with FFT-based spectral measures results in a multivariate measurement, which corresponds very strongly with perceptions of voice quality. (Awan, 2011) Very little evidence is available which applies cepstral measurements to voices of children at different ages. This information is important because it would allow us to understand how structural changes in children's vocal folds correspond to acoustic changes, not only during sustained vocalization but also in the naturalistic context of connected speech.

PURPOSE

The purpose of this study was to investigate the effect of female age on acoustic measures of voice production. To accomplish this we recorded female children and adult speakers producing vowels and sentences, which were then subjected to acoustic analysis. Specific research questions included: (1) Does female age affect CPP in vowels and sentences? (2) Does female age affect fundamental frequency in vowels and sentences? Based on previous literature and known anatomical differences in children and adults, the hypotheses were that measures of fundamental frequency and cepstral peak would be significantly different across all stimuli. Specifically, we hypothesized that adult females would manifest higher measures of CPP and lower fundamental frequency measures than children.

METHODS

Participants

Participants for this investigation were 34 females recruited into two different age groups: child (between 6-10 years; mean= 8.47 years; standard deviation=1.61 years) and young adult (between 19 – 25 years of age; mean=20.35 years; standard deviation=1.64 years). Inclusion criteria required participants to have no history of diagnosed voice disorders (dysphonia lasting greater than 2 weeks for which a medical evaluation was sought), neurological motor impairment, or current upper respiratory infection at time of participation.

Instrumentation

Equipment for this study consisted of the KayPentax (Montvale, NJ) Computerized Speech Lab (CSL) and the software program PRAAT. The CSL digitized and recorded analog signals produced by speakers, which were input to the CSL from an AKG Acoustics (Northridge, CA) head-mounted microphone. The microphone head was placed approximately 3cm from the corner of the mouth. All recorded signals were sampled at 11,025Hz and saved to a desktop computer. PRAAT was used to obtain all dependent variables.

Procedures

All participants were recorded in the Laryngeal Function Laboratory in the Miller Speech and Hearing Clinic. Participants were informed of the procedure and the participant, or a parent or guardian, read and signed a consent form. Once consented, the head-mounted microphone was placed on them. Participants were recorded saying three different utterances that included the following:

a) They produced the vowels /i/ and /a/, with the following instructions: "*Take an easy breath in, and say the vowel /i/ (or /a/) at a comfortable pitch and loudness, as steady as you can, until I say stop. I will ask you to stop after 5 or 6 seconds*."

b) They produced the fifth sentence from the Consensus Auditory Perception Evaluation of Voice (CAPE-V), "*Peter will keep at the peak*." After being asked to read the sentence silently they were asked to produce it. If the child or adult demonstrated reading abilities with ease they received the following instructions:
"*Please read each of these sentences at a comfortable pitch and loudness, just as if you were talking to me in a conversation. Make sure you take an easy breath in before reading each sentence*."

If the child was unable to read with ease, the child was asked to repeat each sentence with the following instruction:

"Please repeat each of these sentences at a comfortable pitch and

loudness, just as if you were talking to me in conversation. Make sure you take an easy breath before each sentence."

Analyses

The PRAAT program was used to calculate two different measurements from the three-recorded stimuli (two vowels and one sentence): (1) Fundamental frequency (F_o - the average rate of vocal fold vibration, as measured from the cepstrum), (2) cepstral peak prominence (CPP). The relationship between independent and dependent variables acquired is illustrated in Table 1.

Table 1. Dependent Variables

Stimulus	**Measurements (dependent variables)**	
Vowel /i/	F_o (Hz)	Cepstral Peak (dB)
Vowel /a/	F_o (Hz)	Cepstral Peak (dB)
Sentence	F_o (Hz)	Cepstral Peak (dB)

To investigate the research questions, two different types of analyses were applied to the data. To investigate the effect of age on acoustic measurements, six separate one-way ANOVAS were applied to the CPP data and F_o data, with group (child vs. adult) as a between-group factor. An ad-hoc analysis was also conducted to further investigate the effect of stimulus type of acoustic measures, pooled across groups. Six separate paired t-tests were applied to either the CPP or F_o data for each possible stimulus pair (e.g., /i/ vs. /a/; /i/ vs speech; /a/ vs. speech). For all comparisons, the level of significance was set at alpha = 0.05.

RESULTS

Descriptive statistics for the two female age groups are illustrated in Table 2. Specific to measures of CPP, the children displayed higher values during production of the two vowels compared to adults, although the absolute difference was only 1.42dB and 1.46dB for the /a/ and /i/ vowels, respectively. Alternatively, the children exhibited lower values during connected speech compared to the adult females, though the difference was very small (0.25dB). For measure of F_o, female children always manifested higher values than the adults regardless of the stimulus. Variability was very similar between the two groups across all dependent variables.

Table 2. Descriptive statistics for the two comparison groups.

Measure		Mean (dB)	Standard Deviation
CPPa	Adult	21.14	2.07
	Child	22.56	2.43
CPPi	Adult	21.72	1.71
	Child	23.18	2.36
CPPspeech	Adult	17.28	.59
	Child	17.03	1.05
Foa	Adult	242.47	21.54
	Child	270.29	30.43
Foi	Adult	253.06	14.99

	Child	292.35	33.91
Fospeech	Adult	215.59	27.49
	Child	249.59	20.60

Six separate one-way ANOVAs were applied to the data. Results are illustrated in Table 3. For measures of CPP the only significant effect was found during the production of the vowel /i/ (F[32] = 4.3, p = 0.45). This finding indicated that the children exhibited significantly higher values of CPP during production of /i/ than the adults. The effect size for this difference between children and adult females was moderate, with *d* = 0.71. However, children exhibited significantly different values of F_o than adults in all stimuli. These findings indicated that female children manifest significantly higher values of F_o across all speaking conditions. Effect sizes were large for all F_o comparisons, with F_o /a/ *d* = 1.06, F_o /i/ *d* = 1.49, and F_o speech *d* = 1.39.

As an ad-hoc analysis, six separate t-tests were applied to CPP and F_o data pooling across age groups so that speaking condition was the only factor. Results are illustrated in table 4. Findings revealed that each set of paired stimuli significantly varied with the exception of CPP during production of the two vowels.

Table 3. Results of six one-way ANOVAs with Group (adult vs. children) as a between-subject factor.

		Sum of Squares	df	Mean Square	F	Sig.
CPPa	Between Groups	17.125	1	17.125	3.360	.076
	Within Groups	163.094	32	5.097		
	Total	180.220	33			
CPPi	Between Groups	18.382	1	18.382	4.334	.045
	Within Groups	135.737	32	4.242		
	Total	154.119	33			
CPPspeech	Between Groups	.534	1	.534	.735	.398
	Within Groups	23.241	32	.726		
	Total	23.774	33			
Foa	Between Groups	6580.265	1	6580.265	9.467	.004
	Within Groups	22241.765	32	695.055		
	Total	28822.029	33			

Foi	Between Groups	13124.235	1	13124.235	19.093	.000
	Within Groups	21996.824	32	687.401		
	Total	35121.059	33			
Fospeech	Between Groups	9826.000	1	9826.000	16.652	.000
	Within Groups	18882.235	32	590.070		
	Total	28708.235	33			

Table 4. Results of six paired t-tests

Paired Samples Statistics

		Mean	N	Std. Deviation	Std Error Mean	Sig.
Pair 1	CPPa	21.85	34	2.337	.40078	.170
	CPPi	22.45	34	2.161	.37062	
Pair 2	CPPa	21.85	34	2.337	.40078	.000
	CPPspeech	17.16	34	.8488	.14557	

Pair 3	CPPi	22.45	34	2.161	.37062	.000
	CPPspeech	17.16	34	.8488	.14557	
Pair 4	Foa	256.38	34	29.553	5.068	.001
	Foi	272.71	34	32.623	5.595	
Pair 5	Foa	256.38	34	29.553	5.068	.000
	Fospeech	232.59	34	29.495	5.058	
Pair 6	Foi	272.71	34	32.623	5.595	.000
	Fospeech	232.59	34	29.495	5.058	

DISCUSSION

The purpose of this study was to investigate the effect of female age on acoustic cepstral measures of voice production. Measures of CPP and F_o were obtained via cepstral analyses in sustained vowels and connected speech produced by female children and young female adults. Results indicated that for most speaking conditions CPP did not differ significantly between the two age groups, with the exception of the sustained /i/ vowel. However, F_o was significantly higher in the female children regardless of speaking condition. These findings partially supported the experimental hypotheses for measures of CPP, but fully supported hypotheses for F_o measurements.

Measures of CPP and F_o are influenced by the properties of vocal fold vibration during phonation. Findings from the current study are supported by a previously published study that utilized laryngeal videostroboscopy to investigate vocal fold vibratory dynamics during phonation in children and adults. Patel, Dubrovskiy, and Dollinger (2014) found that the vibratory motion of vocal folds in children is characterized by increased variability in glottal periodicity, phase asymmetry, and glottal gap index. The findings of the current study indicated that vibration frequency was different across speaking conditions in children compared to young adults, and also that the vowel /i/ demonstrated significantly higher values in children compared to adults. Patel et al. also noted that high cycle-to-cycle variability in periodicity, phase symmetry, and glottal gap index are normative aspects of prepubertal vocal fold motion. Along with the Patel et al. report, these findings support the hypothesis that acoustic output is influenced by changes in the vocal fold structure and the maturing speech mechanisms.

Measures of F_0 were markedly varied between the child and adult female groups in the current study. Stathopoulos, Huber, and Sussman (2011) utilized acoustic recordings from both males and females (ages 4-93 years) to examine changes in acoustic output across the lifespan. Stathopoulos et. al. noted that female participants exhibited a drop in F_0 from 4 to 60 years of age. Both the current study and Stathopoulos et al. attribute the drop in F_o to the increasing length and mass of the vocal folds with vocal maturation. It may be noted that adult participants in the current study were around the age of 20 years, the age when the vocal ligament is fully matured. Acoustic variance between groups may be attributed to the difference in texture of the laryngeal cartilage and surface of the articular faces of the vocal apparatus. Stathopoulos et al. also credited the discrepancy in F_0 to reduced control of vocal fold tension in children. It is also plausible this variability results from laryngeal cartilage development, and the reduced differentiation in the layers of vocal fold structure of young speakers.

Analysis of pooled CPP and F_o revealed significant variation for all groups except for vowels. Awan, Giovinco, and Owens (2012) also found significant effects of vowels on CPP. However, the data in the study from Awan et al. indicated the vowel /i/ to be lower than in the current study. The capability of voice to vary in pitch, loudness, and quality in connected speech could contribute to variation in CPP. Future studies may examine the discrepancy in the vowel /i/ as reported in the current study and that of Awan et al.

A condition that was not controlled for in the current study was the effect of intensity of production on measures of vocal output. Bockmann, Drinnan, Storck, and Carding (2011) found that jitter and shimmer vowel analyses were most heavily influenced by intensity of speech production. Awan et al. also recommended that measures for evaluating voice standardize the equipment and measurements being used (instead of having a speaker utilize a non-habitual voice to accommodate such variations.) This type of measurement, along with normative CPP samples, would help to control the effects that intensity and altered phonation can have on acoustic output and measures of CPP, jitter, and shimmer. Future studies may further examine the effect of intensity of speech production on cepstral measures.

SUMMARY

Cepstral measures of F_o and CPP from female children and adults were used in the present study to examine the effect of age on acoustic measures of voice production. The results indicated that CPP did not differ significantly between the two age groups, with the exception of the sustained /i/ vowel. However, as anticipated, F_o was significantly higher in the female children regardless of speaking condition. Future studies might center on the investigation of vowel and CPP output to explore the discrepancy in trends for vowels and CPP measures in the current and past studies. The development of normative CPP measurements would also aid in clinical application of the present, and other, findings regarding cepstral voice data.

REFERENCES

1. Awan, S. Analysis of Dysphonia in Speech and Voice (ADSV) An Application Guide 2011; Issue A: pp. 1-4.

2. Awan S., Giovinco A., Owens J. Effects of Vocal Intensity and Vowel Type on Cepstral Analysis of Voice 2012; Journal of Voice Vol. 26 No. 5. PP. 670.e15-670.e20.

3. Bennett S. A 3-Year Longitudinal Study of School-Aged Children's Fundamental Frequencies 1983; Journal of Speech and Hearing Research Vol. 26: pp.137-142.

4. Boone D., Mcfarlane S., Von Berg S., Zraick R. The Voice and Voice Therapy 2014; Ninth Edition: 34-47.

5. Brockmann M., Carding P., Drinnan M., Storck C. Reliable Jitter and Shimmer Measurements in Voice Clinics: The Relevance of Vowel, Gender, Vocal Intensity, and the Fundamental Frequency Effects in a Typical Clinical Task 2011; Journal of Voice Vol. 25 No. 1. Pp. 44-53.

6. Dolinger M., Dubrovskiy D., Patel R. Characterizing Vibratory Kinematics in Children and Adults with High-Speed Digital Imaging 2014; Journal of Speech, Language, and Hearing Research Vol. 57. Pp. S674-S686.

7. Drumright D., King D., Seikel J. Anatomy and Physiology for Speech, Language and Hearing 2010; Fourth Edition: pp.165-222.

8. Garrel R., Giovanni A., Nazarian B., Nicollas R., Ouaknine M., Triglia J. Normal Voice in Children Between 6 and 12 Years of Age: Database and Nonlinear Analysis 2007; Journal of Voice Vol. 22 No. 6: pp.671-675.

9. Gerdeman B., Glaze L., Stemple J.. Clinical Voice Pathology Theory and Management 1999; Second Edition: 36-46.

10. Huber J., Stathopoulos E., Sussman J. Changes in Acoustic Characteristics of Voice Across the Life Span: Measures from Individuals 4-93 Years of Age 2011; Journal of Speech, Language, and Hearing Research Vol. 54. Pp. 1011-1021.

11. Sergeant D., Welch G. Age-Related Changes in Long-Term Average Spectra of Children's Voices 2007;Journal of Voice Vol. 22 No. 6: pp.658-670.