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Voice initiation and voice offset patterns in normal females: investigated by high speed digital imaging

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VOICE INITIATION AND VOICE OFFSET PATTERNS IN NORMAL FEMALES: INVESTIGATED BY HIGH SPEED DIGITAL IMAGING

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ABSTRACT

This preliminary study investigated the voice initiation period (VIP) and voice offset period (VOP) using high-speed digital imaging. The purpose of the study was to obtain preliminary data on VIP and VOP patterns of normal voice and to investigate the variability in VIP and VOP patterns in young female subjects within and between recording sessions. VIP was segmented into 3 phases: VIPa, VIPb, and VIPc. Results of the analysis of the data demonstrated that VOP is a more consistent measure than VIP and that VIPa is the most consistent phase of VIP. This study also suggested that changes in fundamental frequency and intensity may affect the number of glottic cycles necessary to complete VIP segments but not the VOP.

1 INTRODUCTION

The American Speech-Language-Hearing Association (ASHA) defines voice disorders as being characterized by the abnormal production and/or absence of vocal quality, pitch, loudness, resonance, and/or duration, given an individual's age and/or sex. Of the total working population in the United States, approximately 25% have jobs that critically require voice use, and 3% of the working population has occupations in which their voice is necessary for public safety (ASHA, 1993). According to conservative estimates, approximately 28 million workers in the U.S. experience voice problems daily (Verdolini & Ramig, 2001). It is estimated that 3% to 9% of the general population of the United States has a voice disorder (ASHA, 1993).

Voice disorders can have tremendous negative effects on the social, emotional, and vocational aspects of an individual's life (Roy, Merrill, Gray, & Smith, 2005). They can also significantly affect the quality of life of the people by limiting their choices of professions, or by causing loss of work either temporarily or permanently, especially for those whose jobs require extensive use of voice (e.g., teachers, singers, actors, politicians, and news reporters). This has tremendous financial and emotional implications not only for the person but for also their family and society.

Before appropriate treatment for voice disorders can be recommended, a proper diagnosis must be made. A diagnosis for a voice disorder is usually based on either indirect and/or direct measures. Indirect measures include aerodynamic, vibratory, and acoustic measures. These measures can provide valuable clinical information pertaining to change in fundamental frequency, phonation range, vocal intensity, and perturbation measures due to the voice disorder. However, these measurements do not involve visualization of the vocal fold. Therefore, the

examiner must infer what is happening at the level of the vocal fold vibrations (Colton, Casper, & Leonard, 2005). Direct measures include Videostroboscopy (Colton, Casper, & Leonard, 2005), Kymography (Wittenberg, Tigges, Mergell, & Eysholdt, 2000), and High-Speed Digital Imaging (HSDI) (Yan, Ahmad, Kunduk, & Bless, 2005; Kuduk, Yan, McWhorter, Bless, 2006). These measures provide a direct image of the vocal folds and their vibratory characteristics (Colton et al.). The laryngeal imaging techniques provide valuable information regarding size, extent and depth of the lesions that result in irregular vocal fold vibrations which contribute significantly to the change of vocal quality.

Videostroboscopy is currently the primary technique used to view the behavior of the vocal folds in most voice clinics (Colton et al., 2005). Videostroboscopy was designed to allow the examiner to gather information on the vibratory nature of the vocal cords. It involves the use of a strobe light which is controlled by the fundamental frequency of the vocalization. Each pulse of light actually illuminates a different point of the vibratory cycle and the fragmented sections become fused by the human eye due to the phenomenon of Talbot's law (Baken & Orlikoff, 2000). Therefore, what is actually seen are illuminated points from different phonatory cycles which are fused to provide an average vibratory pattern (Kunduk, 2004). The videostroboscopic image provides much valuable information pertaining to the vocal fold vibration and laryngeal function. Clinicians generally place considerable importance on findings related to glottal closure, the mucosal wave, and the presence of any non-vibrating segments since this information aids the diagnosis and treatment plan (Colton et al) for the voice disturbance. However, this technique is based on regular vibration, and it is very limited in demonstrating the irregular vocal fold vibratory characteristics of the vocal folds which is commonly found in voice disorders (Tigges, Wittenberg, Mergell, & Eysholdt, 1999). Even though, videostroboscopy is a

valuable tool to examine symmetric and, regular vocal fold vibrations, it has significant limitations for investigating severely irregular vocal fold vibration, short phonation segments and cannot capture short and chaotic segments such as phonation onset and offset (Kunduk, 2004).

New emerging laryngeal imaging techniques such as HSDI and Kymography are promising and are thought to address the limitations of current laryngeal imaging techniques such as videostroboscopy in diagnoses of voice disorders and their treatment. Previously, only sustained vocal fold vibration has been analyzed when diagnosing and evaluating voice disorders. However, HSDI acquires images at a much faster rate (Videostroboscopy captures vocal folds at 30-35 frames per second as oppose to commercially available High Speed Digital Imaging (HSDI) systems such as Kay Elemetrics can record images of the vocal folds up to 8000fps), allowing for a frame-by-frame evaluation of the vocal folds' dynamic behavior. Both HSDI and Kymography allow more detailed analysis of vocal fold vibration during phonation. Kymography produces an image that represents movement at a single horizontal line whereas HSDI examines the full length of the vocal folds. These techniques with their faster capturing rate allow the observation of the voice initiation period (VIP) and voice offset period (VOP) and subtle changes in normal and disordered voices during sustained phonation.

The VIP was described as the time period from the initial movement of the vocal folds from resting position to regular vibration (Kunduk et al., 2006). The VOP on the other hand was described as the time from the first abduction motion of the arytenoids to complete cessation of vocal fold oscillation (Kunduk et al., 2006).

Literature Review

The rationale for studying VIP is similar to previous studies that have examined Voice Onset Time (VOT). When utilizing acoustic measures, VOT is defined as the period between the release of an oral constriction/noise burst and the onset of periodic voicing. VOT patterns can vary according to the phonetic context of the speech material being examined (Whiteside, Dobbin, & Henry, 2003). Since VOT plays a key role in speech timing, production, and perception, it has been the basis of many studies (Whiteside et al., 2003). Morris, McCrea, and Herring (2008) conducted a study to measure the VOTs in CV syllables produced by young adult males and female when the phonetic environment and speech tempo were controlled. They determined that the overall mean VOTs in the voiced and voiceless plosive syllables were similar for the men and women. The study also indicated that there was a significant difference across vowels, with the plosives before /a/ having shorter VOTs than those before /i/ or /u/. In addition, they found that VOTs also varied by place of production with longer VOTs for alveolar and velar plosives than for bilabial plosives.

Whiteside et al. (2003) investigated the patterns of the VOT patterns of voiceless and voiced plosives as a function of age in male and female preadolescent and adolescent children. It also aimed to evaluate the relevance and importance of variability in speech production within a developmental framework of the acquisition and mastery of motor speech behavior. The study concluded that a developmental trend existed in the variability patterns in VOT, which was characterized by a decrease in variability between age 5;8 and 11;10 years. These results of declining variability are suggestive of maturing motor speech skills as children approach adolescence.

McCrea and Morris (2007) conducted a study to determine the effect of vocal training in VOTs during speaking and singing among females and to examine if speech versus singing significantly affected the VOTs. This study indicated that VOTs were similar for trained and untrained singers. It also determined that differences in mean VOT between speech and singing were significant for /p/ but not for /b/. Results revealed both groups of subjects (trained and untrained singers) used longer VOTs for /p/ production during the speech task than singing task.

Few investigations have been done regarding the diagnostic value of VOT. However, one study by Edgar, Sapienza, Bidus, and Ludlow (2001) utilized acoustic analysis of patients with abductor spasmodic dysphonia (ABSD) to determine which acoustic measures differed from controls and were independent factors representing patients' voice control difficulties. It also aimed to determine whether acoustic measures related to blinded perceptual counts of the symptom frequency in the same patients. Speech samples were obtained of patients diagnosed with ABSD and of a control group consisting of adults with no evidence of a voice disorder. The samples were preamplified and recorded to digital audiotape, and the acoustic waveform was displayed using CSpeech 4.0. The VOT was measured for four voiceless consonants. Results indicated that VOT differences between phonemes were not different. However, they did indicate that the ABSD group had longer VOTs than the controls.

Several other studies involving VOT have been conducted, but most of these studies were based on indirect measures and had conflicting results. For example, Neiman et al. (1983) did not find variations in the VOT duration of younger and older females whereas Liss et al. (1990), reported variations in this measure between younger and older males (as cited in Kunduk, 2004). Weismer and Fromm (1983) reported that differences in VOT measures may be influenced by supraglottal factors (such as duration of stop closure) and the maximum displacement of the

vocal fold tissue (as cited in Kunduk, 2004). Since these indirect measures do not include direct visualization of the vocal folds, visualization of the brief phase of initiation of vibration of the vocal folds should be of immense value in determining the contribution of vocal fold vibration patterns to these timing measures. This direct visualization is possible with HSDI.

Previous studies analyzing voice initiation period (VIP) through high speed imaging are also scarce. One study by Tigges et al. (1999) utilized digital video kymography to investigate phonation onset which they defined as the interval from the prephonatory adduction movement to the initial point of steady vibration. This study evaluated the initiation of a hard onset compared to a normal onset. It revealed that the prephonatory standstill for the hard onset is longer than in normal initiation. However, this study and similar studies utilizing kymography are limiting because anterior-posterior modes of vibration cannot be demonstrated.

One study by Kunduk et al. (2006) involved using HSDI to analyze the VIP. This study defined VIP as the time period between the first vocal fold contact to regular vibration. Careful evaluation of the VIP initial time period indicated that first vocal fold contact is followed by an irregular vibration which organizes into a regular vibration. The study aimed to determine if vocal folds in the aged larynx take longer to achieve regular vibration than vocal folds in the younger larynx. The study showed that the VIP period in the older subject was characterized by a slow increase in glottal opening whereas the younger subject demonstrated a sharp increase in glottal opening. In addition, it was determined that compared to the younger subject, the older subject took a longer number of frames for the vocal fold vibration to come to a complete stop. Furthermore, this study also aimed to determine if the Voice Offset Period (VOP) could provide insight into the structural makeup of the vocal folds and its relationship to vibration. VOP was easily determined in the younger subject. However, it was more difficult in the older subject due

to variation in vibrations. Results indicated that there was an apparent difference in vibratory offset behaviors of the older subject compared to the younger subject (Kunduk et al.).

Another study by Braunschweig, Flaschka, Schelhorn-Neise, and Dollinger (2008) presented an objective method for the differential diagnosis of functional dysphonias using the in-stationary dynamics of vocal fold vibrations during the phonation onset. This method included the use of an endoscopic digital high-speed recording (HSR). HSR yield High-Speed-Glottograms (HSG) which is visualization of the deflections of the edges of the vocal folds extracted over time. HSG's were analyzed to determine the phonation onset's dependency between recorded sound pressure and the rate of exponential increase of the amplitudes for both vocal folds during phonation onset. Results indicated that subjects could be successfully classified in normal voices, hypofunctional dysphonia and hyperfunctional dysphonia. Therefore, the study demonstrated the applicability of high-speed recordings as a medical diagnosis tool for functional voice disorders.

Yan et al. (2005) conducted a study which demonstrated that HSDI has great potential in differential diagnosis of voice disorders by providing a means to establish new clinical protocols and measurement parameters and that it provides valuable information on the glottal opening and closing patterns. It also can potentially provide a means to determine the effectiveness of treatment that results in improved but not necessarily normal voice. In addition, the study suggests that HSDI may help explain variations obtained from the indirect acoustic measures and ultimately improve the acoustic analysis measures due to the fact that HSDI systems allow for the simultaneous acquisition of acoustic signals with the image recordings.

Purpose of Current Study

Because studies analyzing VIP and VOP are rare, the importance of VIP and VOP as assessment tools for voice disorders is not fully known. However, one can reasonably assume that it could provide much valuable information in the assessment of laryngeal function since VIP and VOP might be influenced by factors such as myogenic, airflow and vocal folds tissue characteristics. The primary purpose of this study is: (1) to obtain preliminary data on VIP and VOP patterns of normal voice, and (2) to investigate the variability in VIP and VOP patterns in young females subjects within the same and between different recording sessions.

2 METHODS

Subjects

Fourteen females between 18 and 29 years of age participated in the study. Data were obtained from a previously Institutional Review Board (IRB) approved study and were used again for the purpose of this study. The previous study confirmed that all of the subjects were non-smokers with no history of dysphonia or hearing problems. All of the subjects were recruited from the campus of Louisiana State University (LSU) in Baton Rouge, Louisiana. All measures were not analyzed for all 14 participants. Instead 8 of 14 provided data to examine VIP variability within the same session and between 2 different sessions; the other 6 subjects were not included in the analysis due to missing VI P data in the recordings. Eleven of 14 female subjects were used to determine the variability of VOP across 2 different session; the other three were not included in the analysis of VOP due to incomplete data set. See appendix A, B, and C for table of raw data**.** In addition to the 14 participants, 1 healthy subject was used to investigate the effects of fundamental frequency and intensity on VIP and VOP patterns.

Data Collection and Analysis

Data was collected from HSDI recordings used in the previous IRB approved project. For the previous study, KAY Elemetrics, High –Speed Video System, Model 9710, was used to collect the data. Subjects were instructed to produce /i/ (as in **e**at) at a comfortable pitch and loudness. The recordings were performed at a 2000 frames/sec rate by using a specially designed, multi-port, super sensitive camera for eight seconds of recording. The images were captured at 384Mb/sec into high-speed video RAM with gray scale resolution of 160 x 140. Images were obtained with a rigid 70° endoscope (KAY Elemetrics, 9106) with a 300-watt-

coldlight source (Olympus CLV-U20). The rigid laryngoscope was coupled to the high-speed digital camera head and endoscopy was performed as in conventional videostroboscopy (Kay Pentax, 2008).

For the current study, these images were analyzed using Kay's Image Processing Software (KIPS). KIPS analyzed video images recorded by Kay's High Speed Video System which recorded and stored the images natively in AVI format. Researcher utilized the "Montage Creation" function on KIPS to determine an accurate point of voice initiation, regularity of phonation and voice offset period. Montage is a time sequence series of images that allows clear viewing glottal cycle as it changes from one frame to the next. It allowed the observation of changes in glottal area from one cycle to next. This montage also allowed the examiner to see several cycles of vocal fold vibration and allowed the examiner to estimate the maximum glottal area opening and its sameness from one cycle to the next (Kay Pentax, 2008).

Determining VIP and VOP

VIP and VOP were determined using KIPS and were included in the analysis. VIP was divided into three sections: (a) VIPa begins with the first change of direction of the true vocal fold edges and ends with the first contact along any portion of the vocal folds (Figure 1a). (b)VIPb begins with the first contact of the vocal folds and ends with the first contact along the full length of the vocal folds which coincides with the opening of the vocal processes (Figure 1b). (c) VIPc begins with the first contact along the full length of the vocal folds ends when regularity of vibratory cycle is obtained, which begins with the first cycle that reaches the maximal glottal area. Specifically, VIPc is determined by counting the number of cycles

beginning with the last cycle of VIPb and ending when the glottal area is identical to a still image of the maximal glottal area during sustained phonation (Figure 1c).

To calculate VOP, the examiner counted the number of cycles from the last contact of the vocal folds to complete cessation of vocal fold oscillation at the end of phonation.

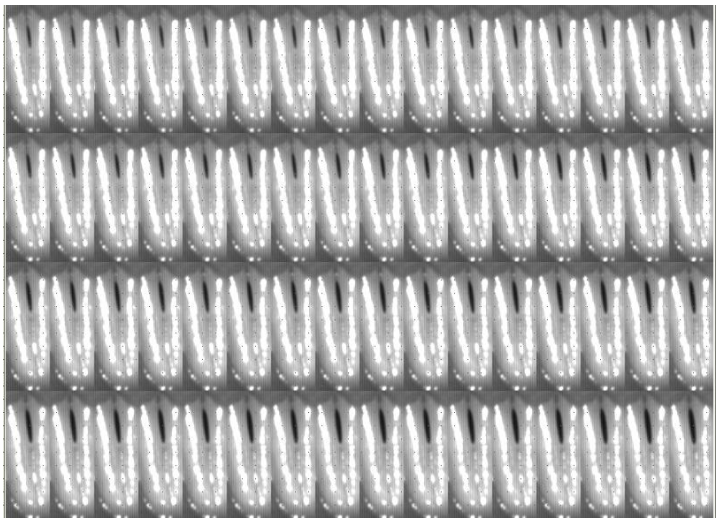

Figure 1: First contact of vocal folds from abducted position for getting ready to vibrate. Each frame shows the slow opening of the vocal folds to get ready for vibration. No change in the direction of vocal folds is observed during this stage. The vocal folds are getting ready for VIPa stage.

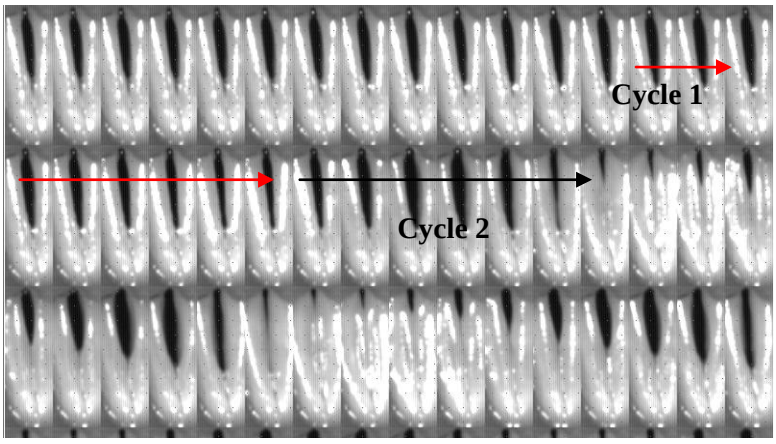

Figure 2: Voice initiation period from first opening to first vocal fold contact (VIPa). Three glottis cycles are determined by the change of direction of the vocal folds during the first initiation of vibration.

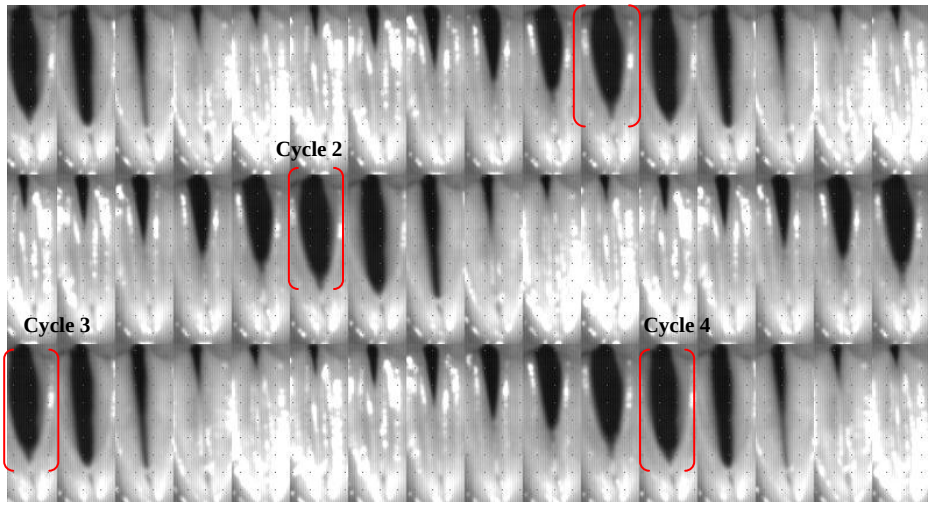

Figure 3: Determination of regular vocal fold vibration. This was achieved by observing when the maximum open glottal area the glottal area is identical to a still image of the maximal glottal area during sustained phonation.

Variability of VIP and VOP patterns were determined by counting the number of glottal cycles within the same recording session and between different recording sessions for each subject. Within the same recording session variability was determined by comparing the subject's data from two phonations segments within the same recording. The number of glottal cycle difference for each subject between different recording sessions was also determined. To determine the variability between different recording sessions, the mean of the subject's VIP and VOP segments on day one were compared to the mean of the subjects VIP and VOP segments on day two.

Fundamental Frequency and Intensity

The effects of fundamental frequency (pitch) and intensity (loudness) variation on VIP and VOP patterns were also investigated. One healthy female subject produced nine different phonation tasks (low-pitch/soft-loudness, low-pitch/normal-loudness, low-pitch/loud-loudness, normal-pitch/soft-loudness, normal-pitch/normal-loudness, normal-pitch/loud-loudness, high-

pitch/soft-loudness, high-pitch/normal-loudness, and high-pitch/soft-loudness). The effects of each different phonation tasks on VIP and VOP were determined.

Reliability

To determine intra-judge reliability of for VIPa, VIPb, VIPc, VIPabc, and VOP measurement techniques, 10% of data was randomly chosen and re-analyzed. Pearson correlation coefficient for intra-judge reliability of measurement techniques showed significant correlation at 0.01 level between the first and second measurement (correlation coefficient: 0.995)

3 RESULTS

Distribution of VIP Measures within the Same Recording Session

VIPa consists of number of cycles beginning with the first change of direction of the true vocal fold edges and ending with the first contact along any portion of the vocal folds. The range of VIPa values for two phonation segment within the same recording differed between 1-6 glottic cycles. The highest glottic cycle difference within the subjects was 5 glottic cycles for subject number 6. For the seven other subjects, the variability remained between zero and 2 glottic cycles.

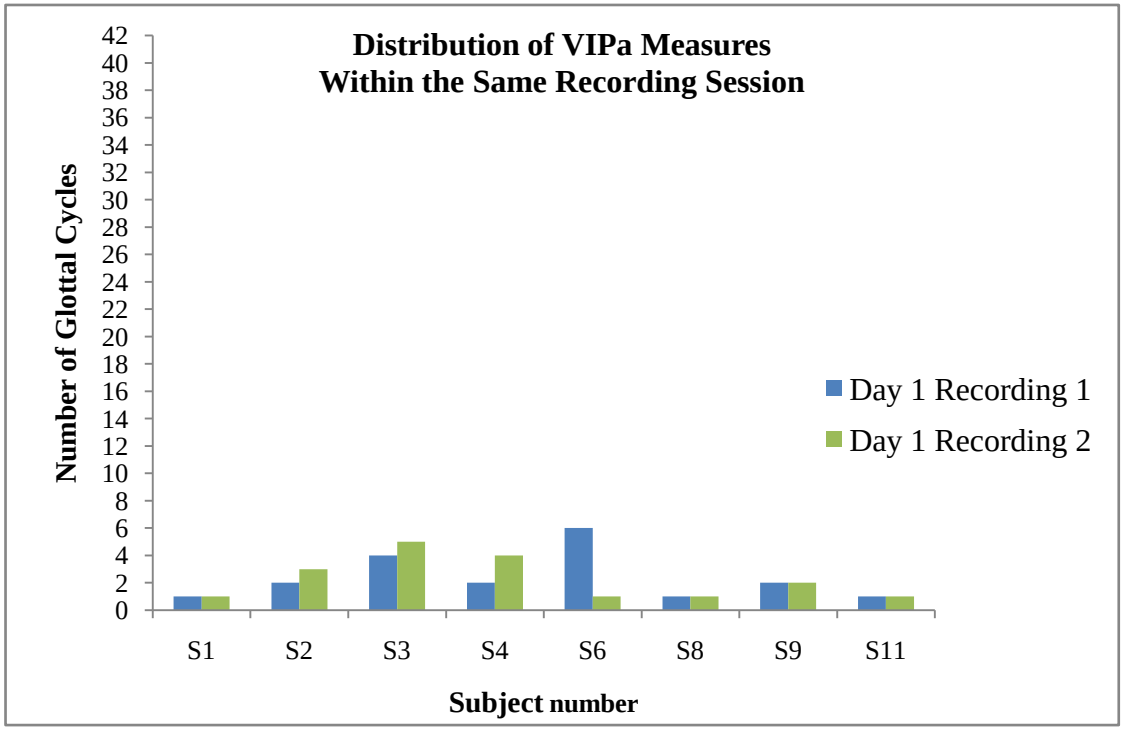

Figure 4: Distribution of Voice Initiation Period segment A (VIPa) number of glottic cycles within the same recording for each subject. VIPa consists of the number of glottic cycles beginning with the first change of direction of the true vocal fold edges and ending with the first contact along any portion of the vocal folds.

VIPb consists of the number of cycles from the first contact along the vocal folds to the first opening of the vocal processes as an indication of involvement of the full vocal fold length in vibration. The subjects (N: 8) completed the VIPb segment between 1 and 32 glottic cycles for two phonation segments within the same recording session. The highest glottic cycle difference within the subjects was 13 glottic cycles for subject number 8. For six subjects, the variability remained between 1 and 4 glottic cycles (Figure 3 and Appendix A).

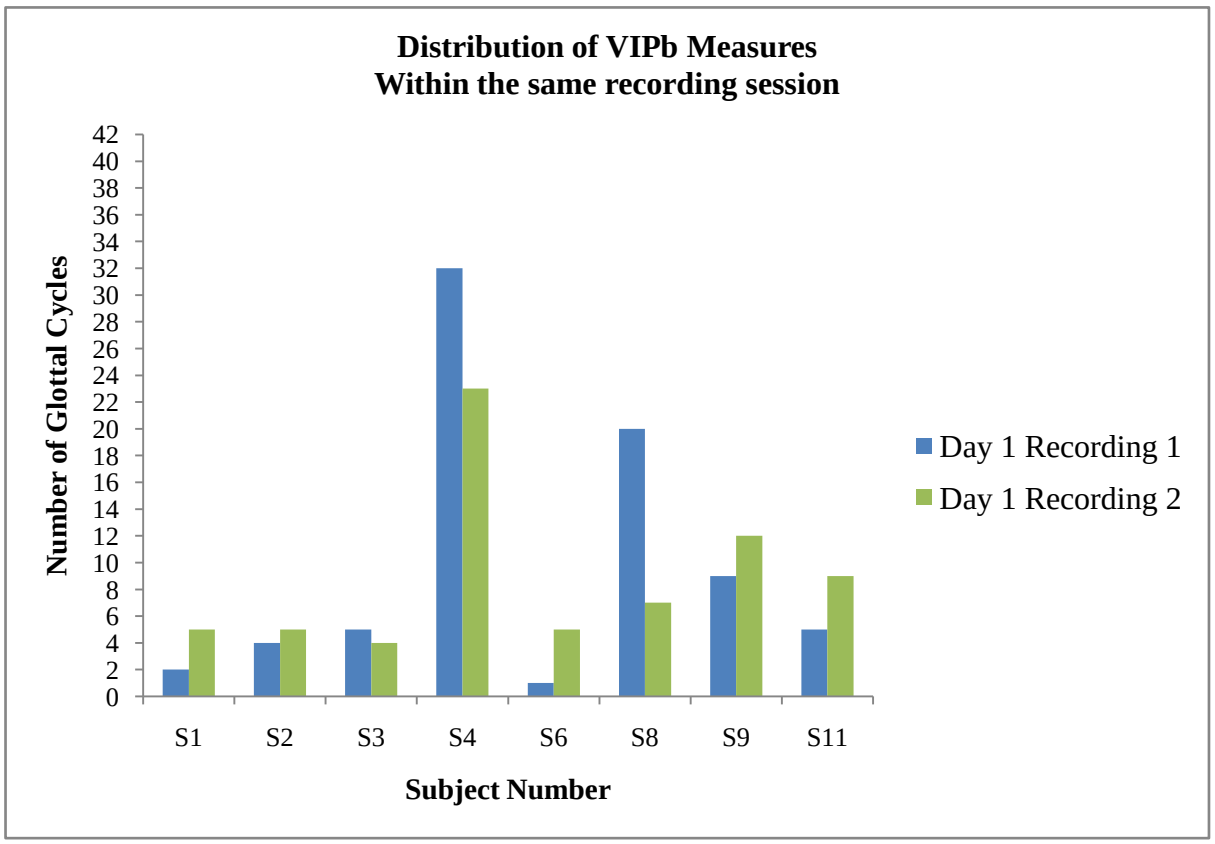

Figure 5**:** Distribution of Voice Initiation Period segment B (VIPb) number of glottic cycles within the same recording for each subject. VIPb consists of the number of glottic cycles beginning with the first contact along the vocal folds and ending with the first opening of the vocal processes which coincides with the first contact along the full length of the vocal folds.

VIPc segment consists of the number of cycles beginning with the opening of the vocal processes and ending with maximum glottal opening. The subjects (N: 8) completed VIPc

segment in between 3 and 15 glottic cycles for two phonation segments within the same recording session. The highest glottis cycle difference within the subjects was 6 glottic cycles for subject number 9. For six subjects, the variability for two phonation segments within the same recording session remained between 0 and 2 glottic cycles (Figure 4).

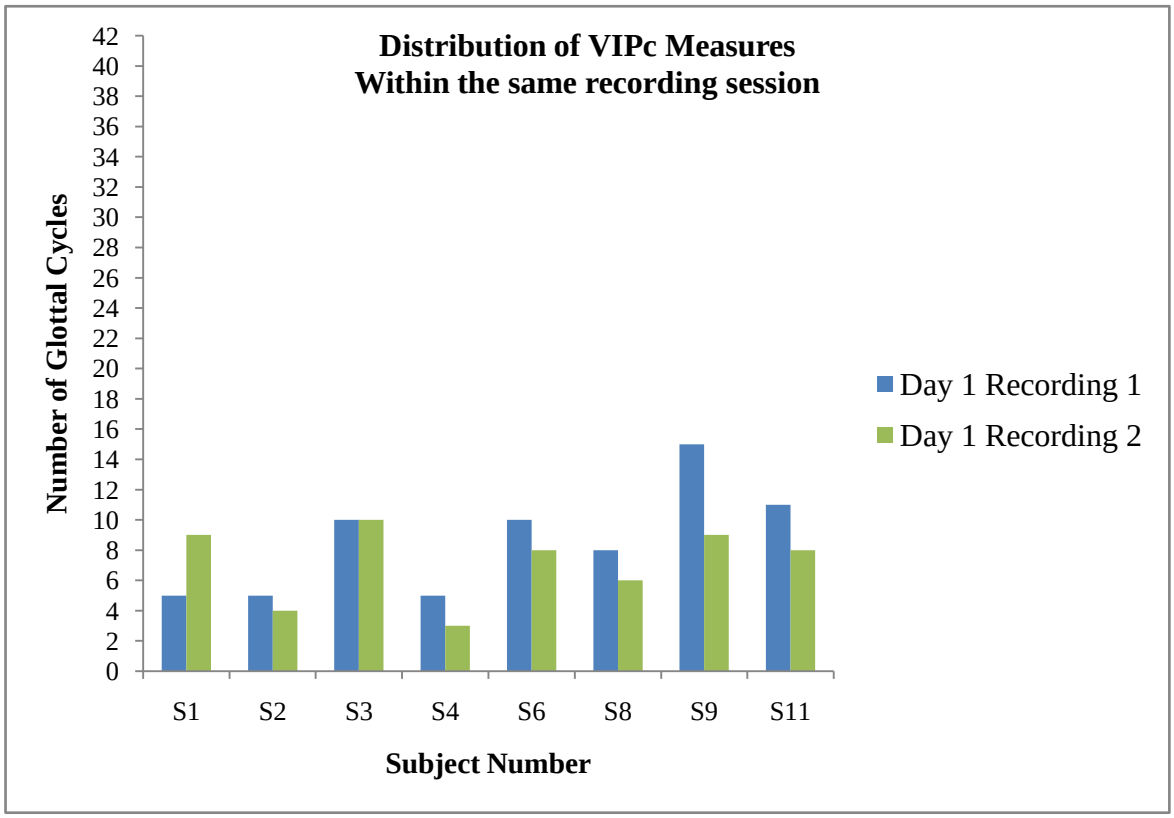

Figure 6: Distribution of Voice Initiation Period segment C (VIPc) number of glottic cycles within the same recording for each subject. VIPc consists of the number of glottic cycles beginning with the opening of the vocal processes and ending when regularity of vibratory cycle is obtained, which coincides with the maximum glottal opening.

VIPabc consist of the sum of the number of glottic cycles of VIPa, VIPb, and VIPc. The subjects (N: 8) completed VIPabc segment in between 8 and 39 glottic cycles. The highest glottic cycle difference within the subjects was 15 glottic cycles for subject number 8 (Figure 5).

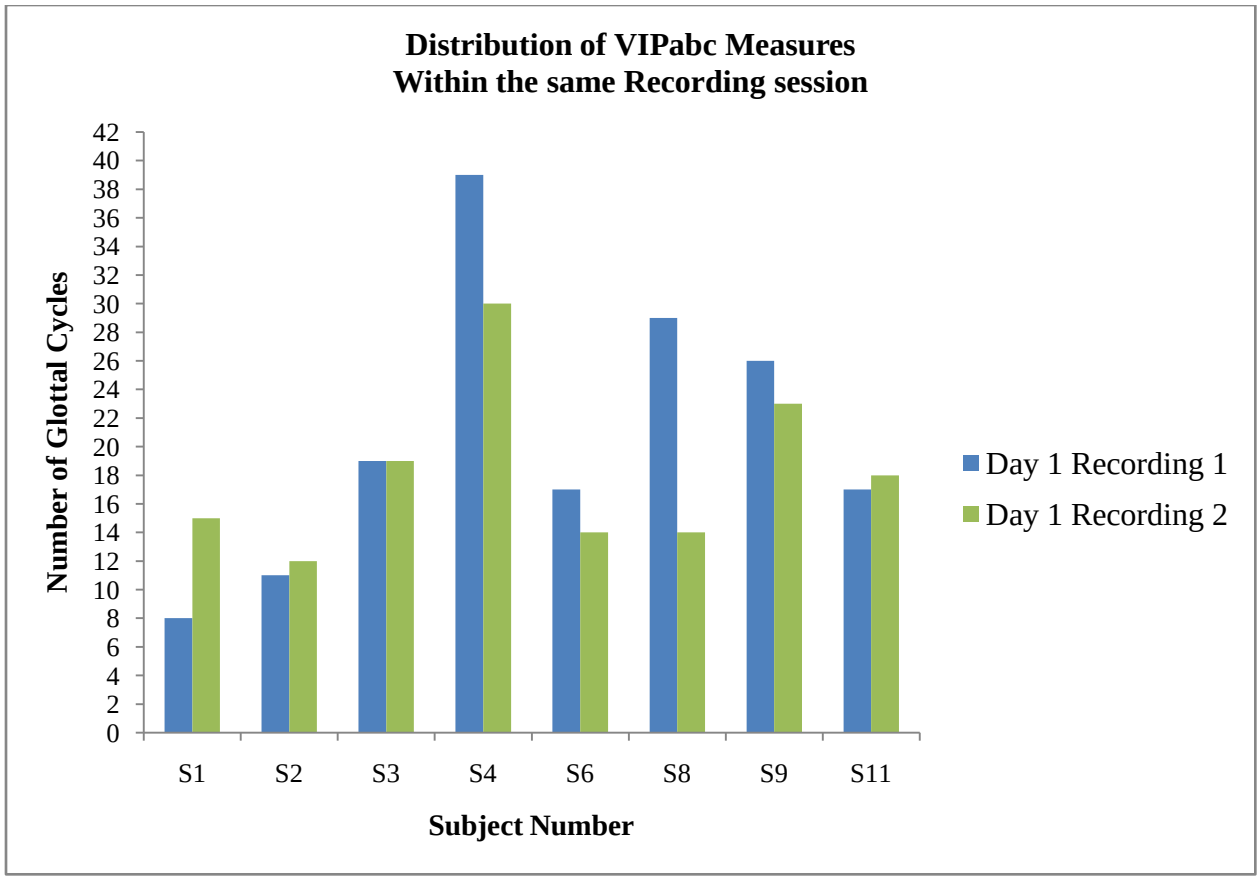

Figure 7: Distribution of Voice Initiation Period segment ABC (VIPabc) number of glottic cycles within the same recording for each subject. VIPabc consists of the sum of the number of glottic cycles of Voice Initiation Period segment A (VIPa), Voice Initiation Period segment B (VIPb), and Voice Initiation Period segment (VIPc).

Distribution of VIP and VOP Measures between Different Recording Sessions

The maximum difference for VIPa for a young female subject (S6) between different recording sessions was 2 glottic cycles between different recording sessions (Day 1: mean 2 with a standard deviation of 2; Day 2: mean 2 with a standard deviation of 1; see table 1). The seven remaining subjects varied between 0-1 glottic cycles for this segment of VIP (Figure 6).

Table 1: Range, Mean, and Standard Deviation of Voice Initiation Period segment A (VIPa): Voice Initiation Period segment B (VIPb), Voice Initiation Period segment C (VIPabc), and Voice Initiation Period segment ABC (VIPabc) of 8 young females between 2 different days. VIPa consists of the number of glottic cycles beginning with the first change of direction of the true vocal fold edges and ending with the first contact of the vocal folds. VIPb consists of the number of glottic cycles from the first contact of vocal folds to the first opening of the vocal processes. VIPc consists of the number of glottic cycles from opening of the vocal processes to when regularity of vibratory cycle is obtained. VIPabc consists of the sum of the number of glottic cycles of the sum of VIPa, VIPb, and VIPc.

	VIPa		VIPb		VIPc		VIPabc	
	Day1	Day2	Day 1	Day2	Day 1	Day 2	Day 1	Day 2
Mean	2	2	9	6	8	9	19	17
STD	2	1	9	3	3	3	8	4
Range	1-6	1-4	2-32	4-13	4-15	4-13	8-39	14-23

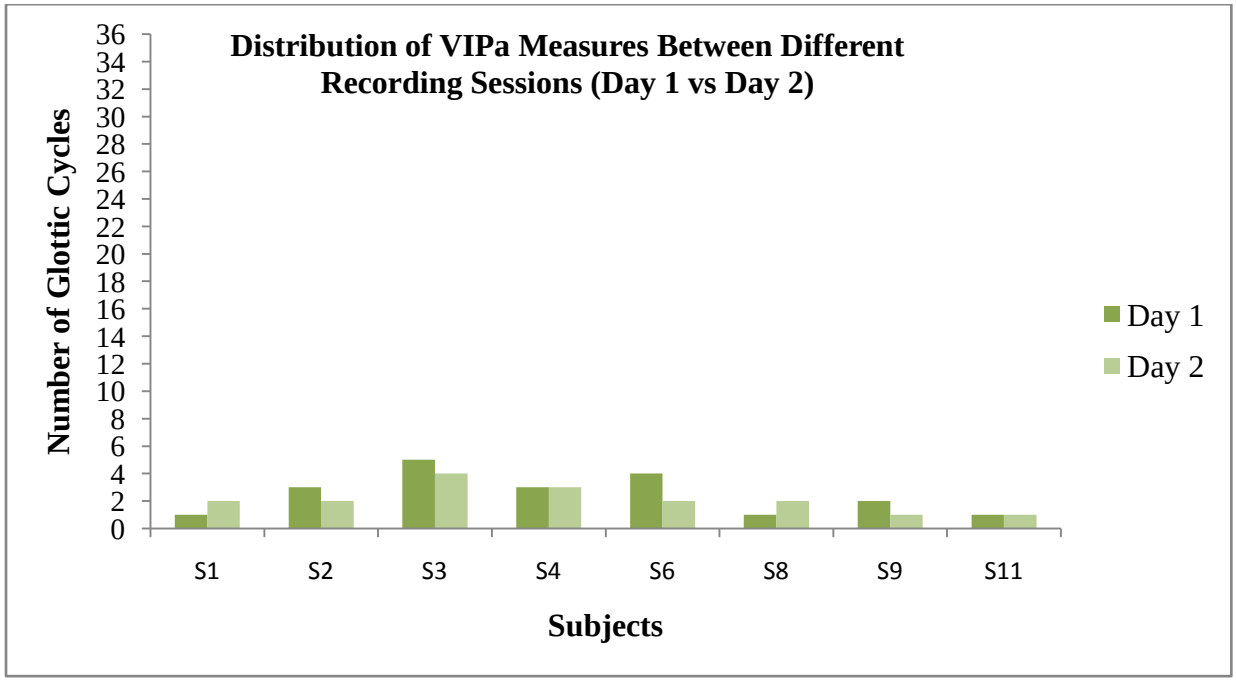

Figure 8: Distribution of Voice Initiation Period segment A (VIPa) number of glottic cycles between different days for each subject. VIPa consists of the number of glottic cycles beginning with the first change of direction of the true vocal fold edges and ending with the first contact.

VIPb differed between 0 and 23 glottic cycles between different day recording sessions (Day1: mean 9with a standard deviation of 9; Day2: mean 6 and a standard deviation of 3). Two subjects obtained the highest number of glottic cycles differences for VIP b (S4:23 glottic cycles; S8:11 glottic cycles). Remaining subjects showed between 0 and 2 glottic cycles over two different recording sessions (Figure 7).

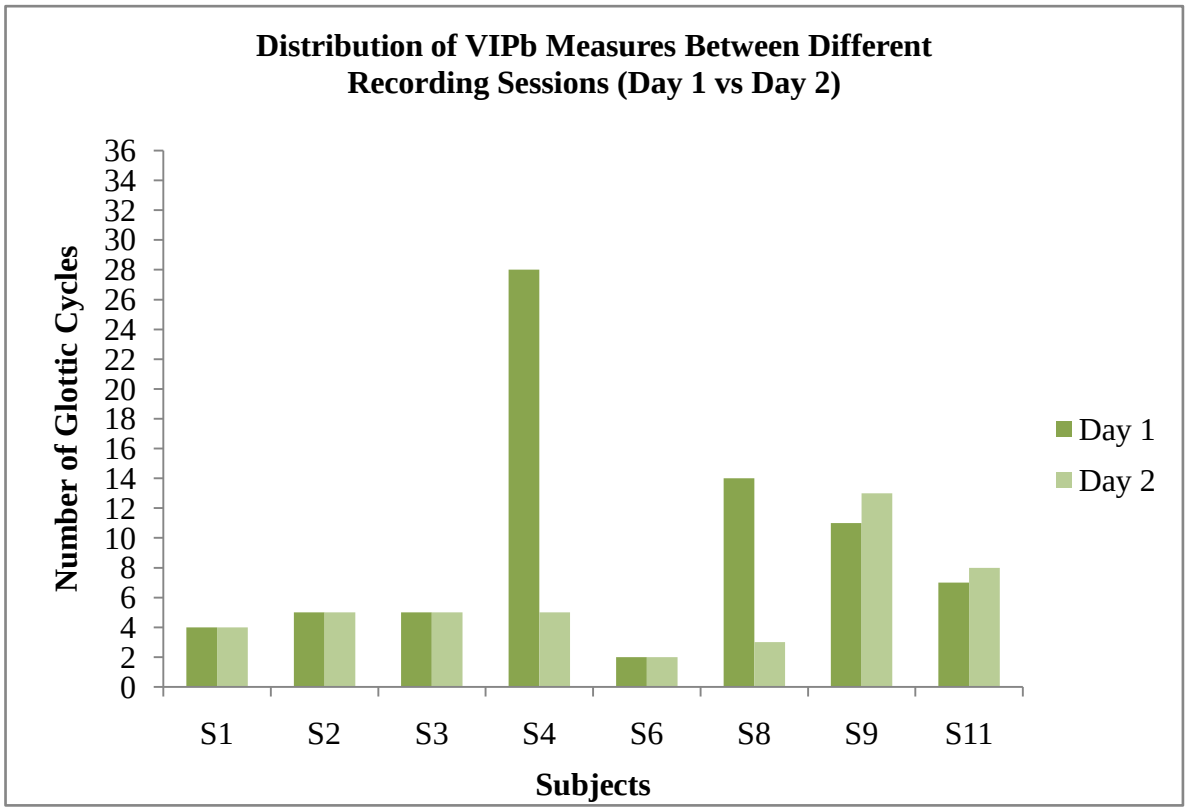

Figure 9**:** Distribution of Voice Initiation Period segment B (VIPb) number of glottic between different days for each subject. VIPb consists of the number of glottic cycles beginning with the first contact along the vocal folds and ending with the first opening of the vocal processes which coincides with the first contact along the full length of the vocal folds.

VIPc differed between 1and 6 glottic cycles between different day recording sessions for subjects (Day1: mean 8 with a standard deviation of 3; Day 2: mean 9 with a standard deviation of 3). Only one subject (S1) differed by 6 glottic cycles between days with the rest of subjects differing only 1-4 glottic cycles (Figure 8).

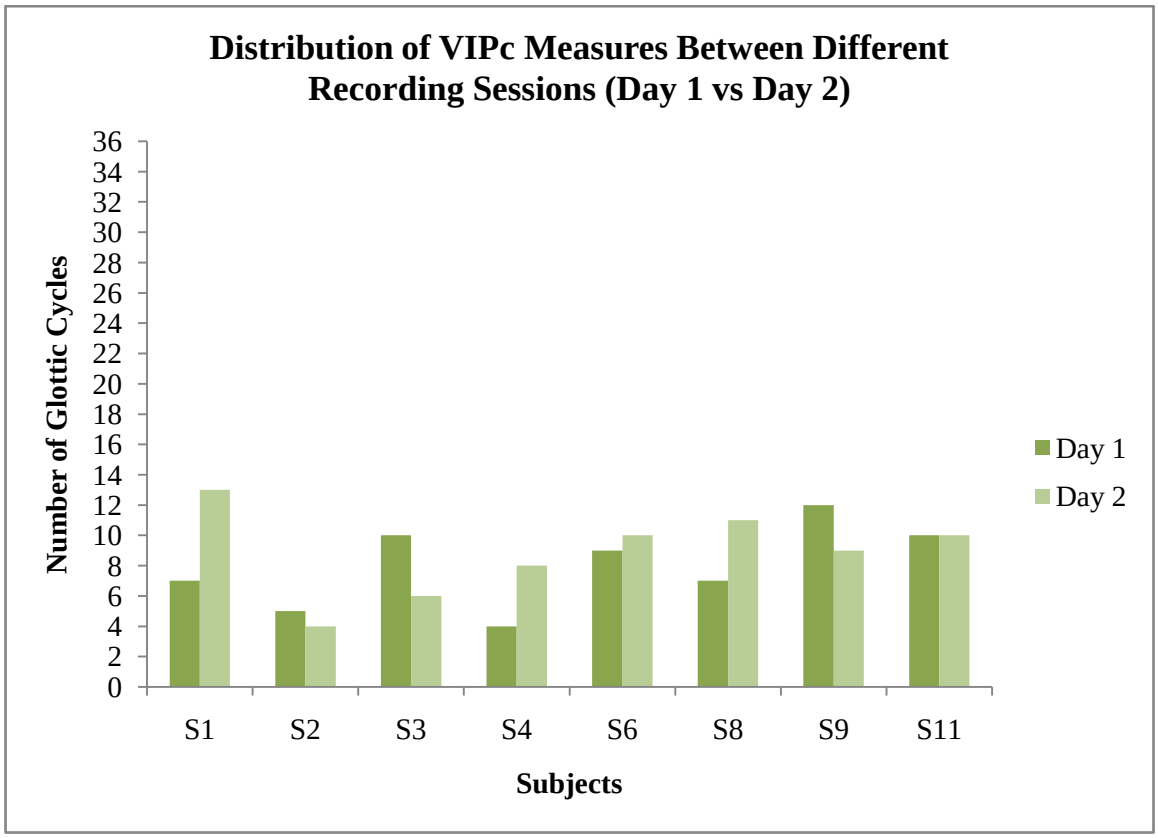

Figure 10: Distribution of Voice Initiation Period segment C (VIPc) number of glottic between different days for each subject. VIPc consists of the number of glottic cycles beginning with the opening of the vocal processes and ending when regularity of vibratory cycle is obtained, which coincides with the maximum glottal opening.

VIP abc differed between 0 and 19 glottic cycles between different day recording sessions (Day 1: mean 19 with a standard deviation of 8; Day 2: mean 17 with a standard deviation of 4). Only one subject demonstrated difference between different recordings reaching 19 glottic cycles. The rest of the subjects differed between 0-7 cycles between two different recording sessions (Figure 9).

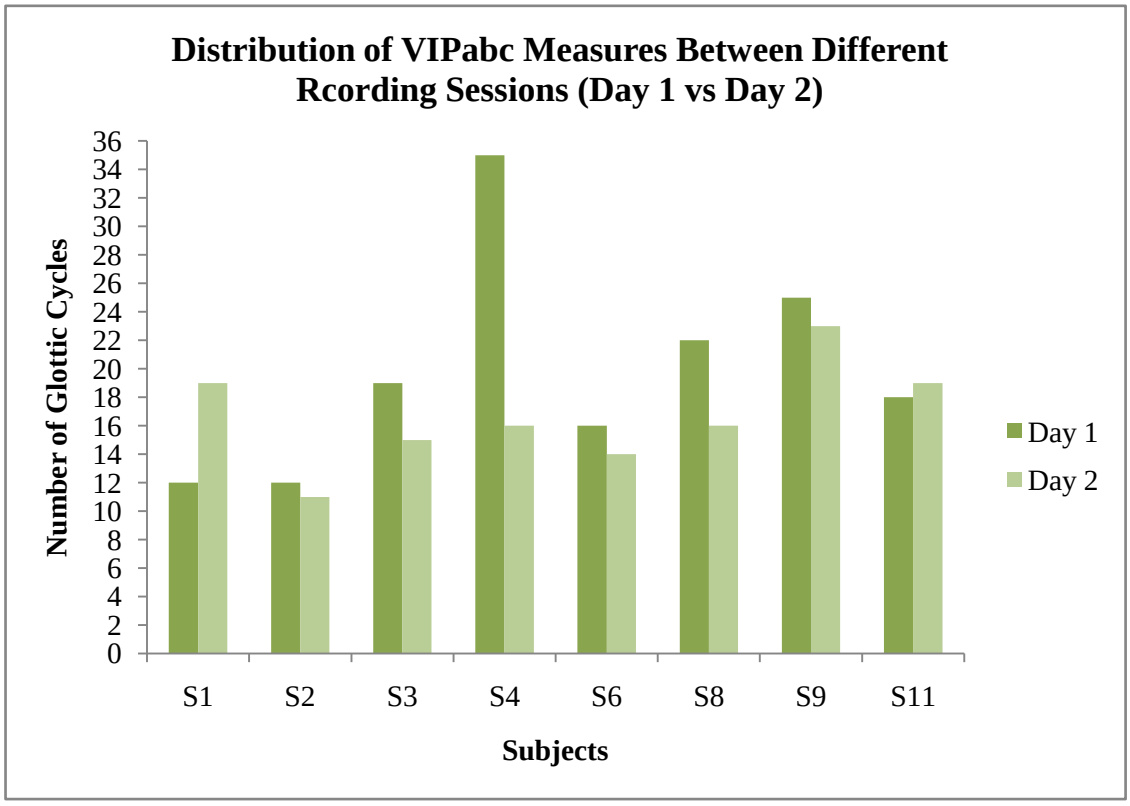

Figure 11: Distribution of Voice Initiation Period segment ABC (VIPabc) number of glottic cycles between different days for each subject. VIPabc consists of the sum of the number of glottic cycles of Voice Initiation Period segment A (VIPa), Voice Initiation Period segment B (VIPb), and Voice Initiation Period segment (VIPc).

VOP values for young subjects differed between 0 and 6 glottic cycles between different recording sessions. (Day 1: mean 10 with a standard deviation of 3; Day 2: mean 11 with a standard deviation of 4). Except 3 subjects, all subjects differed between 0-2 glottic cycles.

Table 2: Range, Mean, and Standard Deviation of Voice Offset Period (VOP) of 13 young females between 2 different days. VOP consists of the number of glottic cycles beginning with the last contact of the vocals and ending with complete cessation of vocal fold oscillation at the end of phonation.

VOP		
	Day 1	Day 2
Mean	10	11
STD	3	4
Range	8-15	6-17

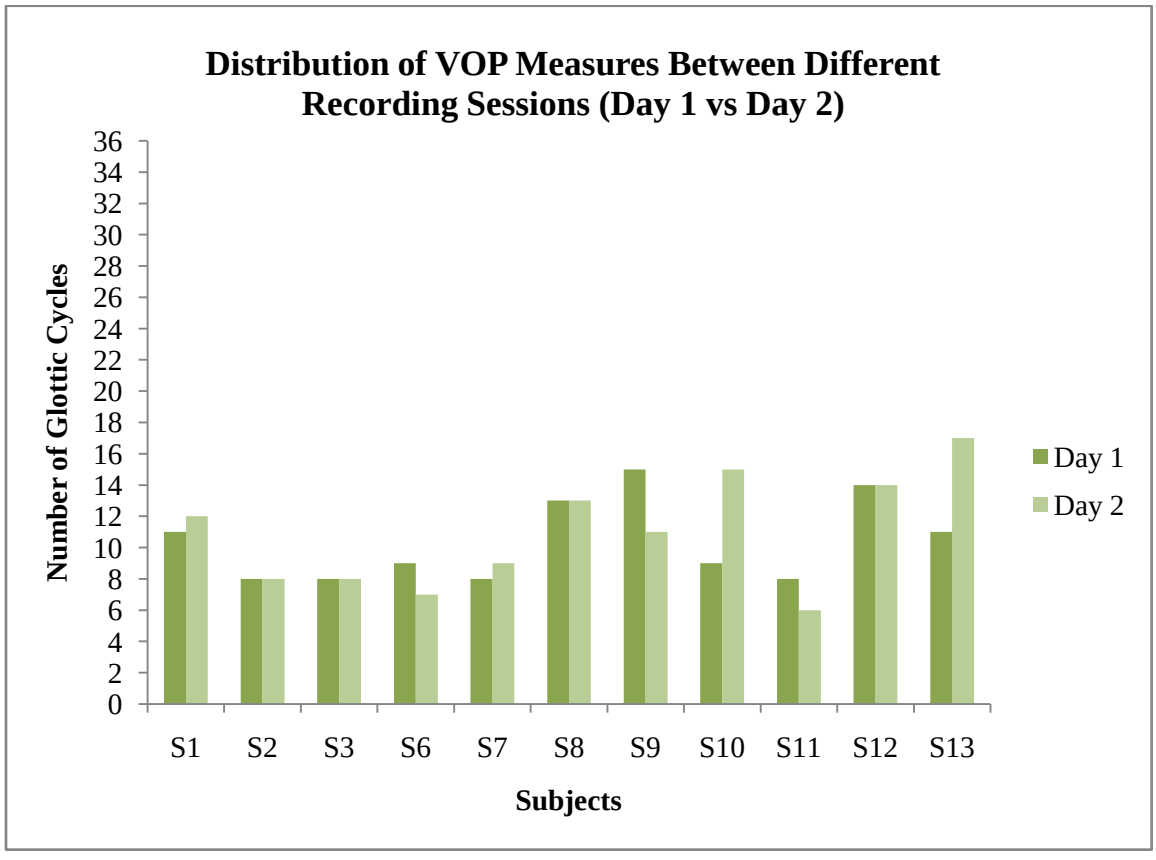

Figure 12: Distribution of Voice Offset Period segment ABC (VOP) number of glottic cycles between different days for each subject. VOP consists of the number of glottic cycles beginning with the last contact of the vocals and ending with complete cessation of vocal fold oscillation at the end of phonation.

Affects of Fundamental Frequency and Intensity Variation on VIP and VOP

Nine different combinations of pitch and loudness were obtained from one subject to determine the effects of different phonation types on VIP and VOP measures (high-pitch/soft loudness, high-pitch/normal-loudness, high-pitch/loud-loudness, normal-pitch/soft-loudness, normal-pitch/normal-loudness, normal-pitch/loud-loudness, low-pitch/soft-loudness, low-pitch/normal-loudness, low-pitch/loud-loudness). The number of glottic cycles for VIPa, VIPb, VIPc, VIPabc, and VOP was determined for two phonation segments during the same recording for each of the 9 combinations. The average of the two trials was calculated and used for analysis because the two trials were very consistent within each combination.

High-pitch/soft-loudness phonation resulted in the highest number of glottic cycles to complete VIPa segment (Number of glottic cycles: 10). The rest of phonation types were completed within 2 and 5 cycles (Table 3).

Table 3: Comparison of number of glottic cycles present for Voice Initiation Period segment A (VIPa) for combinations of pitch (high, normal, low) and loudness (soft, normal, loud) produced by a single subject. VIPa consists of the number of glottic cycles beginning with the first change of direction of the true vocal fold edges and ending with the first contact along any portion of the vocal folds.

VIPa			
	Loudness		
Pitch	Soft	Normal	Loud
High	10	5	4
Normal	5	2	3
Low	3	2	2

Low-pitch phonation with differing loudness (especially normal and loud loudness) resulted in the highest number of glottic cycles for VIPb compared to other combinations of pitch and loudness. Loudness change for the high and normal pitch phonations completed VIPb within 1 and 3 glottic cycles (Table 4).

Table 4: Comparison of number of glottic cycles present for Voice Initiation Period segment B (VIPb) for combinations of pitch (high, normal, low) and loudness (soft, normal, loud) produced by a single subject. VIPb consists of the number of glottic cycles beginning with the first contact along the edges of the true vocal folds and ending with the first opening of the vocal processes which coincides with the first contact along the full length of the vocal folds.

VIPb			
	Loudness		
Pitch	Soft	Normal	Loud
High	1	1	2
Normal	1	3	1
Low	1	9	7

Soft-loudness phonation appeared to shorten the VIPc compare to other combination of pitch and loudness. VIPc was lengthened by the increase in loudness for normal-pitch phonations. The number of glottic cycles for normal-pitch/normal-loudness phonation (14 glottic cycles) was more than double the number of glottic cycles for normal-pitch/soft-loudness phonation (5 glottic cycles; Table 5).

Table 5: Comparison of number of glottic cycles present for Voice Initiation Period segment C (VIPc) for combinations of pitch (high, normal, low) and loudness (soft, normal, loud) produced by a single subject. VIPc consists of the number of glottic cycles beginning with the opening of the vocal processes and ending when regularity of vibratory cycle is obtained.

VIPc			
	Loudness		
Pitch	Soft	Normal	Loud
High	5	12	12
Normal	5	14	12
Low	8	8	10

The shortest VIPabc was achieved with low-pitch/soft-loudness (13 glottic cycles). The other phonation tasks appeared to be within 3 glottic cycles of each other without any distinct pattern (Table 6).

Table 6: Comparison of number of glottic cycles present for Voice Initiation Period segment ABC (VIPabc) for combinations of pitch (high, normal, low) and loudness (soft, normal, loud) produced by a single subject. VIPabc consists of the sum of the number of glottic cycles of VIPa, VIPb, and VIPc.

VIPabc			
	Loudness		
Pitch	Soft	Normal	Loud
High	16	18	17
Normal	16	19	16
Low	13	19	19

VOP was the shortest for low-pitch/normal-loudness (5 glottic cycles). Number of glottic cycles for VOP was ranged from 6-8 for all other phonation combinations (Table 7).

Table 7: Comparison of number of glottic cycles present for Voice Offset Period (VOP) for combinations of pitch (high, normal, low) and loudness (soft, normal, loud) produced by single subject. VOP consists of the number of glottic cycles beginning with the last contact of the vocals and ending with complete cessation of vocal fold oscillation at the end of phonation.

VOP			
	Loudness		
Pitch	Soft	Normal	Loud
High	8	7	7
Normal	8	8	6
Low	8	5	7

4 DISCUSSION

The goal of this study was to obtain preliminary data on VIP and VOP patterns of young females with normal voices within the same and different day recording sessions. The preliminary findings suggests that VIPa and VOP measures are the most consistent measures within the same recording session and between different recording sessions in normal, young females (Figures 1, 5, and 9). In addition, this study suggested that changes in fundamental frequency and intensity may affect the number of glottic cycles necessary to complete VIPa, VIPb, and VIPc segments but not the VOP measure in a single subject. This study used data that subjects produced during voicing with a comfortable pitch and loudness (which is assumed to reflect the subject's normal pitch and loudness) during the HSDI recordings. Therefore, variability within and between recording sessions for VIP and VOP data was assumed to be most similar with the normal-pitch/normal-loudness phonation types when compared to Fo/intensity variation data obtained from a single subject.

VIPa appeared to be the most consistent segment of phonation during the VIP measures within and between recording sessions. The criterion for VIPa was easily established from the HSDI data due its distinct characteristics. All but one subject's (S6) variability remained within 0-2 glottic cycles within the same recording sessions. All subjects varied only 1-2 glottic cycles for VIPa between different recording sessions. This finding suggests that VIPa can be measured consistently and its value to distinguish age, gender and different causes of voice disorders should be further explored.

Study findings suggest that VIPa is most affected by high-pitch/soft-loudness phonations in the subject where this data was available. This finding is in line with the expectation that high

frequency phonation with inadequate intensity should result in vocal folds taking longer to vibrate. (Titze, I., Schmidt, & Titze, M., 1995) Furthermore, this finding is supported by the physiologic bases of the vocal fold vibration. During high pitch phonation, vocal folds are tense and therefore have higher glottal resistance and phonation threshold pressure (Jiang, Lin, and Hanson, 2008). Therefore, it will take longer for the vocal folds to achieve vibration.

The range of glottic cycles necessary to complete VIPb was between 2 and 28 glottic cycles. The subject (S4) who obtained the highest VIPb values within the same recording sessions (VIPb: 32 and 23) also demonstrated the highest VIPb value difference between different recording sessions (Day 1 VIPb: 28 glottic cycles; Day 2 VIPb: 5 glottic cycles). With the present study's findings, it is unknown as to whether this subject is an outlier or representative of normal variation for this phase of VIP. Future studies with more specific Fo and intensity guidelines during the voice production and HSDI data capturing are necessary to determine the true range of VIPb. The investigation of the effects of fundamental frequency and loudness variations on VIPb in a single subject revealed that this segment of VIP appeared to increase most if the voice production was low pitch with increasing loudness. For this subject, all other combinations of frequency and loudness remained within 2 glottic cycles of each other for this phase of VIP.

The range of glottic cycles necessary to complete VIPc was between 4-15 cycles among the young female subjects. Variability within the same recording session remained within 6 cycles. The biggest variability within a subject between different recording sessions was 6 glottic cycles. VIPc values obtained from one subject for differing pitch and loudness demonstrated that VIPc appeared to be shortest during soft phonation with high and normal pitch voice production (5 glottic cycles). The wide variability in VIPb and VIPc data might be

induced by the subjective determination of the glottic area increase. In the future, the variability may be reduced by using a quantitative method to determine the regularity of vocal fold vibration when such a method becomes available for clinical use.

Cooke, Ludlow, Hallett, and Selbie (1997) examined whether quantitative differences in vocal fold kinematics could be determined during three types of voice onset: hard, breathy, and normal onset. They asked their subjects to imitate these different phonation onset patterns and investigated their effects on onset of phonatory vibration and used videostroboscopy to investigate this phase of phonation. They reported that the speed, timing, and stiffness of vocal fold adduction differed among voice onset types. They found that onset of phonatory vibration was longest for hard onsets and shortest for breathy onsets. In addition, they determined that hard onsets involved the greatest vocal fold stiffness and breathy onsets involved the least stiffness. In this study, the longest VIPa, VIPb, VIPc, and VIPabc were obtained from different subjects. Close analysis of the current study's data showed no hyper adduction of vocal folds at the initiation of vocal fold vibration (hyper adduction is an indication of hard glottal attack as described by Cooke et al., 1997). It appears that normal subjects do not frequently employ hard glottal attack or breathy phonation onset during phonation onset. Therefore, our findings cannot be compared to Cooke et al. findings at this point since both the methodology (videostroboscopy vs HSDI) and the phonation segment (pre vocal fold vibration vs. initiation of vibration) investigated appeared to be different. However, further research regarding the effects of imitated as oppose to naturally occurring hard, breathy, and normal onset on VIP and VOP values are needed in the future.

Mergell, Herzel, Wittenberg, Tigges, and Eysholdt (1998) studied the growth of the vocal fold amplitudes during the phonation onset with biomechanical model simulation. They found

that the phonation onset time increased with decreasing subglottal pressure, increasing fundamental frequency, and glottal rest area during onset of phonation. The current study showed in a single subject that, only the VIPa increased during high-pitch/soft-loudness phonation where this change in Fo and intensity were investigated. This trend appeared to be the opposite for VIPb and VIPc. In fact, VIPc was the shortest for high-pitch/soft-loudness phonations. However, VIPabc as a whole demonstrated that the soft phonation with low pitch produced the shortest VIPabc which agrees with the Mergell et al. (1998) findings (Table 6).

Studies by Cooke et al., (1997) and Mergell et al., (1998) showed that voluntary aspects of phonation, such as initiating phonation with hard or soft glottal attack does affect voice onset time. These aforementioned studies' description and measurement of voice onset differed from these study's method. The current study attempted to count the number of cycles before the vocal folds reach their regular vibration as oppose to Mergell et al. study where voice onset was described as the amplitude growth of the vocal fold oscillation. Cooke et al. studied the latency between vocal fold closure and the beginning of vocal fold vibration and the process of vocal fold adduction. It is reasonable to assume that voluntary aspects of phonation might affect the VIP measures since subjects are free to choose how to start voicing. This study did not give subjects any directions regarding the initiation of voicing. In addition, subjects in this study might have reacted to the presence of rigid endoscope in their mouth differently and changed their habitual way of their initiating voice patterns. In order to eliminate the effects of voluntary aspect of phonation, future studies could use flexible naso-endoscope when it becomes feasible to use this endoscope type with HSDI. Further, the examiner could instruct his subject to initiate voice a certain way. For example, the subject could be instructed to take a breath before saying/i/

or hold their breath before the phonation begins to eliminate the variability of different types of voice onsets and their effects on VIP measures.

Studies also showed that subjects with diagnosis of functional voice dysphonias have different voice onset patterns (Braunschweig et al., 2007). These patients demonstrated hyper adduction or hyper adduction of vocal folds before the initiation of voicing. The Current study used subjects with normal voice only. The extent to which VIP values might be affected by voice disorders is unknown at this time.

VOP values appeared to be the most consistent compared to VIP segments in this study. VOP measures within the same sessions recordings were only varied from 0 to 1 glottic cycle. Therefore, this study looked at the difference in VOP between different recording sessions more closely. It appears that 9 out of 11 subjects demonstrated only 1-2 glottic cycle difference between different recording sessions for this measure. In addition, the investigation of the effects of varying fundamental frequency and loudness on VOP revealed similar glottic cycle values across all combinations (Table 7) in the single subject which this data was available. For this subject, it appears that changes in Fo and intensity do not affect VOP to the same extent that it affects voice initiation. VOP's apparent invulnerability to Fo and intensity changes warrants further investigation. Future studies should explore if this phase of phonation can be used to determine the outcome of medical, behavioral, or surgical voice intervention. In addition, they should investigate if VOP measurements can be included as assessment parameter in a clinical voice assessment tool box.

Regner, Tao, Zhuang, and Jiang (2008) conducted a methodological study with 10 excised canine larynges to measure onset and offset phonation threshold flow (PTF) and obtain

an onset-offset ratio. They found that the PTF for voice offset was always less than the onset values of PTF. Our findings agree with Regner et al. (2008) findings in that VIPabc as a total measure of voice onset is longer than VOP Regner et al. study also analyzed the effects of lengthening of vocal folds on PTF values. They determined that both offset and onset of phonation are affected by elongation of vocal folds, which is present with high pitch voice production. However, in the current study, vocal fold elongation did not affect VIPabc (Table 6) which would correspond to the voice onset measures in Regner et al. study. The VOP values did not appear to be affected with the high pitch phonation either (Table 7). Conflicting findings could be due to the fact that Regner et al. utilized canine larynges whereas the current study used only human female subjects.

In summary, this study has shown that VOP is a far more consistent measure within and between recording sessions than VIP. Findings also indicate that among different phases of VIP, VIPa is the most consistent measure within the same recording session and between different recording sessions in normal, young females. Furthermore, this study suggested that changes in fundamental frequency and intensity may affect the number of glottic cycles necessary to complete VIPa, VIPb, and VIPc segments but not VOP for a subject where this data was available. Future studies are needed with more subjects to determine if this study's findings will hold and if the results could be generalized to the young female population. In addition, further research is needed to investigate the value of separating VIP into different phases as VIPa, VIPb, and VIPc or if it will prove more useful if all segments together (VIPabc) is used as a voice assessment parameter. The voice data obtained under more controlled Fo and intensity variations is warranted to confirm and expound on this studies preliminary findings. In addition, future

studies should investigate what other factors, such as gender, sex, and disorder, have effects on VIP and VOP.

Limitations of Current Study/Future Studies

This preliminary study's findings on VIP and VOP patterns warrant future studies. In order to generalize its findings regarding VIP and VOP, future studies should address limitations that were present in our study. Data from within and between recording sessions was limited by assuming that the subject's comfortable phonation correlated with normal-pitch/normal-loudness. Therefore, future studies should control Fo and intensity levels. Subjective analysis which relied on visual inspection also limited the reliability and validity of VIP findings and may have increased the variability of the data. Future studies should adopt a more objective glottal area measurement technique to have a more objective and exact values which may decrease variability in the parameters. In addition, the number of subjects of the current study was also a limiting factor. Future studies should include a larger number of subjects and use statistical analysis to determine variability of VIP and VOP.

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APPENDIX A RAW DATA OF WITHIN THE SAME RECORDING SESSION

Raw data of subject's number of glottic cycles for VIPa, VIPb, and VIPc within the same recording session.

Day 1 Recording 1					Day 1 Recording 2			
Subject #	**VIPa**	**VIPb**	**VIPc**	**VIPabc**	**VIPa**	**VIPb**	**VIPc**	**VIPabc**
1	1	2	5	8	1	5	9	15
2	2	4	5	11	3	5	4	12
3	4	5	10	19	5	4	10	19
4	2	32	5	39	4	23	3	30
6	6	1	10	17	1	5	8	14
8	1	20	8	29	1	7	6	14
9	2	9	15	26	2	12	9	23
11	1	5	11	17	1	9	8	18

APPENDIX B RAW DATA OF BETWEEN DIFFERENT SESSIONS (VIP)

Raw data of subject's number of glottic cycles for VIPa, VIPb, and VIPc between different recording sessions.

	VIPa		**VIPb**		**VIPc**		**VIPabc**	
subject #	Day1	Day 2	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
1	1	2	4	4	7	13	12	19
2	3	2	5	5	5	4	12	11
3	5	4	5	5	10	6	19	15
4	3	3	28	5	4	8	35	16
6	5	2	2	2	9	10	16	14
8	1	2	14	3	7	11	22	16
9	2	1	11	13	12	9	25	23
11	1	1	7	8	10	10	18	19
Mean	2	2	9	6	8	9	20	17
Std. Dev	2	1	9	3	3	3	8	4

APPENDIX C RAW DATA OF BETWEEN DIFFERENT SESSIONS (VOP)

Raw data of subject's number of glottic cycles for VOP between different recording sessions.

VOP		
Subject #	Day 1	Day 2
1	11	12
2	8	8
3	8	8
6	9	7
7	8	9
8	13	13
9	15	11
10	9	15
11	8	6
12	14	14
13	11	17
Mean	10	11
Std Dev	3	4

VITA

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