Spring 2015

# The association between the supraglottic activity and glottal stops at the sentence level

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# THE ASSOCIATION BETWEEN THE SUPRAGLOTTIC ACTIVITY AND GLOTTAL STOPS AT THE SENTENCE LEVEL

by

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A thesis submitted in partial fulfillment of
the requirements for the Master of Arts
degree in Speech Pathology and Audiology
in the Graduate College of
The University of Iowa

May 2015

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CERTIFICATE OFAPPROVAL

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MASTER'STHESIS

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This is to certify that the Master's thesis of

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has been approved by the Examining Committee for the thesis requirement for the Master of Arts degree in Speech Pathology and Audiology at the May 2015 graduation.

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**ABSTRACT**

Contrary to the previous belief that any presence of supraglottic activity indicates presence of hyperfunctional vocal pathology, Stager et al. (2000, 2002) found out that supraglottic compressions do occur in normal subjects. In fact, dynamic false vocal fold compressions during production of phrases with a great number of glottal stops were noted. The present study hypothesized that a similar pattern s would be observed at sentence level, where at least 50% or higher incidence of dynamic FVF compressions would be observed at aurally perceived glottal stops and other linguistic markers, such as vowel-initial words, /t/ final words, punctuations and phrase boundaries, where glottal stops were likely to occur.

Nasendoscopic recordings were obtained from 8 healthy subjects (2M; 6F) during production of selected sentence stimuli. Their audio recordings were rated by two judges to detect the location of glottal stops. Then, the video images were analyzed to categorize the presence and absence of dynamic and static false vocal folds (FVF) or anterior posterior (AP) compressions. Results indicated that the incidence of dynamic FVF compressions was 30%. Nevertheless, the average incidence was elevated at aurally perceived glottal stops and at the linguistic contexts that are known to be associated with glottal stops compared to other contexts.

## PUBLIC ABSTRACT

The false vocal folds (FVF), which are situated above our true vocal folds within the larynx or "voice box," come together during swallowing or coughing to protect the airway. At one time, FVF compression while voicing was considered as signs of hyperfunctional voice disorders or maladaptive compensations to vocal fold paralysis. However, Stager et al. (2000, 2002) found frequent brief compressions of the FVF during production of glottal stops (specifically, vowel initiated words) by normal subjects when they recited short phrases. Glottal stops are brief audible cessation of airflow, which can often be heard during phrases such as "We eat eels every Easter."

The present study was designed to further investigate the relationship between FVF compressions and glottal stops and specific linguistic contexts where glottal stops have been known to occur. Eight healthy subjects were recruited. Video images of true and false vocal folds movement and the audio recordings were collected via flexible nasendoscope while they read a set of longer, complex sentences. The incidence of brief or dynamic FVF compressions at aurally perceived glottal stops were only 30%, which was lower than Stager et al.'s results. Nevertheless, elevated frequencies of FVF compressions were noted at words ending with vowels or ending with "T" which were known to be associated with an increased number of glottal stops. This study further elucidated the pattern of normal FVF compressions at certain linguistic contexts. This result will further assist in differentiating normal FVF activity patterns from abnormal patterns and in accurate diagnosis of hyperfunctional voice disorder in clinic settings.

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# INTRODUCTION

The false vocal folds (FVF) also named as ventricular folds, are situated within the larynx superior to the true vocal folds (TVF). Compared to the TVF, much of the histology and functional role of FVF are relatively unknown. It was traditionally assumed that the presence of FVF activity indicated pathology, potentially resulting in laryngeal dysphonia or lesions. Yet, new findings suggest that not only is the presence of the FVF important for vocal resonance, but also its compression can play a role in normal phonations. A deeper understanding of the anatomy of FVF and its normal physiology is crucial for differential diagnosis. For example, we need to be able to accurately differentiate normal FVF activity from hyperadduction, which might be compensatory to TVF hypoadduction (e.g. vocal fold paralysis) or that might be inherent to a hyperfunctional disorder (e.g. adductor spasmodic dysphonia).

The FVF consists of the connective tissue, submucosal glands that lubricate the respiratory tract and TVF, and the muscle fibers. According to Reidenbach (1998), there are three muscular systems within FVF, of which the posterolateral muscular system is an extension of the thyroarytenoid (TA) muscle, containing fast contracting fibers, similar to TA muscle (Guida & Zorzetta, 1997). The three muscular systems adduct the FVF, and are thought to be innervated by the neuron pools that are independent from those innervating the TA muscle. While recurrent laryngeal nerve innervates the TA muscle, the middle branch of internal superior laryngeal nerve (SLN) is transmitted from the sensory receptors of FVF, and the external branch of SLN, which also innervates CT, supplies motor command to FVF (Olthoff et al., 2007; Pinho et al., 1999).

There have been many studies that have associated supraglottic activity with certain pathologies. Woodson et al. (1991) observed supraglottic activity in patients with spasmodic dysphonia. Stager et al. (2000) found medial FVF compression was more frequent in the hyperfunctional group, in comparison to the subjects with nodules and the control. Bielamowicz et al. (2003) argued that static FVF activity increases as a compensatory mechanism for medializing the vocal fold in patients with vocal fold paralysis. On the other hand, normal subjects without vocal disorder have also shown some degrees of supraglottic activity. Stager et al. (2002) observed a high incidence of dynamic FVF compressions in specific linguistic contexts, such as during a glottal stop or vowel repetitions. They also observed a 20% incidence of dynamic A-P compression during articulation of velar and palatal consonants (Stager et al.2002).

One particular interest is that supraglottic activity might be associated with glottal stops (Stager et al., 2002), which is used as a phase boundary marker in a variety of languages (Lindqvist-Gauffin, J., 1969). The criteria for defining glottal stops slightly differ within the linguistics literature. Some define it based on acoustic or perceptual cues while others define it based on the visual cues from the stroboscopy. Umeda (1978) judged glottal stops as a silence in speech waves less than 100ms, or the irregular vibration at the beginning of the vowel. Lindqvist-Gauffin, J. (1969) defined the glottal stops with any of the following criteria: (1) the closure of the glottis; (2) the aryepiglottic closure ("laryngealization"), which is the constriction of the aryepiglottic sphincter (aryepiglotitc muscles, oblique arytenoid muscles, and the thyroepiglottic muscles).

Although the supraglottic activity has been found in both normal subjects and patients with voice disorders, there has been no consensus on what incidence and pattern of supraglottic activity is the objective criteria for hyperfunctionl and normal pattern. Furthermore, the glottal stop which might be inherently associated with the "normal" supraglottic activity, have not been clarified and agreed upon in terms of acoustic and visual criteria. Partially, this might be because the glottal stop is quite a capricious phenomenon. Its frequencies vary greatly amongst speakers, even when reading the same material (Umeda, 1978). The incidence of the glottal stop also depended on the difficulty of the reading material, and on the type of the word (content vs. functional). In addition, while Stager et al. (2002) only targeted glottal stops in vowel-initial tasks, in fact, glottal stops or glottalizations can occur frequently at an allophone of voiceless stops or in word-initial vowels, and at either medial or final phrase boundaries in utterance (Redi & Sattuck-Hufnagel, 2001; Umeda, 1978**).** Thus, investigations into supraglottic activity in various phonological and grammatical conditions where glottal stops have been known to be frequent will validate its association with the glottal stop, and elucidate the normal pattern of supraglottic activity.

Therefore, the first purpose of the study is first to investigate whether our auditory perceptual judgment of the glottal stop matches with the incidence of dynamic A-P and FVF compression from the video endoscopy. In this study, glottal stops will be narrowly defined as the brief cessation of phonation, and a modified Stager et al. (2002)'s qualitative rating scale will be used to describe the supraglottic activity. Secondly, the author will investigate whether dynamic supraglottic activity is relatively increased at locations such as word-initial vowels, voiceless stops and the phrase boundaries, where glottal stops have been known to be frequent.

**More specifically we seek to answer the following questions:**

1. How frequently do glottal stops occur during production of the18 given sentences and phrases?
2. Are glottal stops that are identified perceptually from audio recordings associated with supra glottic activity as judged from nasendoscopic recordings?
3. Is supraglottic activity more likely to occur at vowel-initial words than at consonant-initial words?
4. How frequently do supraglottic compressions occur after a phrase boundary in a complex or compound sentence? Are they context dependent?
5. Is placement of a punctuation mark associated with increased occurrence of supraglottic compressions?
6. How frequent does supraglottic activity occur at /t/-final words?
7. Which phoneme does the maximum degree of supraglottic activity occur?

# LITERATURE REVIEW

## Supraglottic activity and vocal fold disorders

Traditionally, supraglottic activity has been associated with spasmodic dysphonia, plica ventricularis (ventricular phonation), hyperfunctional voice disorders, vocal nodules, unilateral vocal fold paralysis, presbylarynges (a hoarse voice quality due to lack of good glottal closure) (Stager &Bielamowicz, 2010)), and muscle tension dysphonia (Leonard & Kendall, 1998). For example, Woodson et al., 1991) conducted an analysis of 38 spasmodic patients' laryngeal function through flexible laryngoscopy. 33 out of 38 patients showed either false vocal fold (FVF) closure or anterior-posterior (AP) compressions, based on a four point scale (3-TVF fully covered; 0- same width of TVF visible during phonation as in quiet respiration).

Stager et al. (2000) revealed that the increased supraglottic activity correlated with the hyperfunctional voice disorder. They recoded flexible endoscopy for 3 groups (vocal nodule; dysphonia without visible lesions; control who include patients with allergy and acid reflux symptoms) during tasks of sustaining /i/, repeating various syllables, articulating given sentences and during a free conversation.  A speech-language pathologist and an otolaryngologist rated the medial false vocal fold (FVF) adduction and anterior-posterior (A-P) compression of arytenoid cartilages to the petiole of the epiglottis, using 3-point scale (0 =none; 1=adduction without approximation; and 2 = approximation). The consistency was also rated in 3-point scale (0 = absent; 1 = inconsistent; and 2=consistent).The incidence of FVF compression was highest for the hyperfunctional group (80%) regardless of the task, followed by the vocal fold nodules group (68%), and lowest for the control (45%).The incidence of A-P compression was also highest for the hyperfunctional group (92%).

Increased static supraglottic compression was also found in patients with unilateral vocal fold paralysis (UVFP) (Bielamowicz et al., 2003). UVFP patients with normal and abnormal laryngeal function were recruited along with control. The laryngeal function was based on maximum phonation time (MPT), airflow, and intraoral pressure measurements. The minimum/maximum normal value of each category was following: MPT=12.8sec; mean flow=215ml/s; pressure=10.5cm H2O.The glottal area and the width of TVFs (indirectly correlated with static FVF compression) were measured in pixels from transnasal laryngoscopic recordings of sustained /i/ and sniff. The UVFP patients with normal MPT and airflow measures demonstrated smaller glottal gap ratios and increased static unilateral FVF compression activity of nonparalyzed VF (mean=0.624; minimal activity is closest to 1) was greater than paralyzed VF (mean=0.733) and the control (mean=0.807). This indicates that static FVF compression might be a compensatory mechanism for compromised TVF activity.

**Supraglottic activity that has been identified during normal speech production**

Yet, Stager et al. (2000) who compared nodule and hyperfunctional group with control found some degree of FVF and AP compressions in controls with normal laryngeal function. Therefore, mere presence of FVF activity seemed not enough to confirm pathology. In addition, the presence of supraglottic activity might have benefits to laryngeal activity, as demonstrated in the aerodynamic and acoustic study with excised canine larynges (Alipour et al., 2013), FVF medial compression significantly increased subglottal pressure (10 to 20cmH2O) and decreased flow rate (430 to 310ml/s), thus increasing the mean glottal resistance from 2.25 to 4.76 kPa/ (l/s) ($p=.001$). It also increased EGG closed quotient. While A/P also increased EGG closed quotient, it did not affect the glottal resistance (2.31 to 2.27 kPa/ (l/s); $p=0.28$) significantly. Neither type of compressions significantly changed fundamental frequencies. Medial compression increased sound intensity (-21.87 dB to -19.22dB; $p=.058$) in 70% of the larynges while A/P made insignificant change (-21.71dB to -22.36dB; $p=.37$).

Stager et al. (2001) further incorporated quantitative measurement based on single-frame images taken from the flexible endoscope. Their purpose was to quantitatively measure and to compare the static and dynamic components of A-P and FVF compression in normal and pathologic groups. Individuals with vocal complaints (vocal fold nodule or vocal fatigue) and control participants performed following tasks during the transnasal flexible endoscopic examination: sustained /i/ at normal pitch and loudness, syllable repetitions and sentences with glottal stops, and voiced or voiceless phonemes. The images of maximum/minimum FVF compression from frames during TVF adduction and abduction were captured for all given speech tasks. In particular, dynamic FVF compressions were measured from the images during the repeated /i/ task and the articulation of “We eat eels every day.” Supraglottic compressions were rated based on four schematic categories of the proportion of TVF covered. In addition, A-P distance, vocal fold length and vocal fold area were quantitatively measured in units of pixels for each image by two raters: while A-P distance represented A-P compression, vocal fold width (vocal fold area/ vocal fold length) denoted FVF compression. Taking account of intersubject anatomical differences, the raw measurements were normalized, yielding static/dynamic A-P compression and FVF compression. Intrarater and interrator correlations for the measurements were above 0.99 for all, suggesting high reliability. Within subject variance was also small, indicating that the camera-to-larynx distance errors were insignificant. As a result, excessive A-P compression was observed from the voice-disordered group relative to the control**.** On the other hand, there was insignificant difference in the degree of normalized static or dynamic FVF compression across groups (static: normal=.73; nodules=.68; hyperfunctional=.71) (dynamic: normal=.26; nodule=.21; hyperfunctional=.25).This supported the notion that FVF compression is present to some degree in normal speech articulation.

Stager et al. (2002)'s investigation into normal subjects without complaint of voice disorder or sensory pharyngeal symptoms indicated that dynamic supraglottic activity might be normal in certain linguistic context. The authors performed the following tasks during the flexible examination: a sniff, pitch glides, sustained /i/, syllables and repetition of the sentences. Static/dynamic presence of FVF compression and A-P compression or their absence was rated by two SLPs. The activity was assessed at the initiation of the task, throughout the entire task (static) and within a speech task (dynamic). Every individual showed some degree of supraglottic activity. Dynamic FVF compression occurred over 90% during the task with glottal stops. FVF compression was also observed at initiation of prolonged and repeated /i/, and repeated /i-si/ (avg.=34%). Dynamic A-P compression was observed during the tasks with velar and palatal consonants (avg.=20%). This result suggested that dynamic supraglottic activity may be normal during some linguistic or phonetic contexts, especially during glottal stops.

Furthermore, the presence of FVF itself seems to be critical for achieving resonant voice. According to Stager (2011), the mathematical modeling studies have shown that presence of supraglottic structure, with FVF lateralized, favors the oscillations of the TVF while reducing energy dissipation. The patients with supraglottic cancer, who went under supraglottic laryngectomy showed significant decrease in vowel resonance and fewer glottal stops in sentence reading than controls. Patients with only one FVF removed still compressed the remaining FVF dynamically during glottal stops.

**Identifying glottal stops and linguistic contexts where glottal stops are likely to occur**

If glottal stops are associated with supraglottic activity, it is crucial to note various linguistic contexts during which glottal stops are likely to occur so that we may find linguistic contexts associated with increased incidence of supraglottic activity. Then, what are exactly glottal stops? Lindqvist-Gauffin, J. (1969) took an anatomic perspective in defining glottal stops. He argued that glottal stops exist in most languages as markers for pauses or for boundaries between voiced sounds. They involved (1) the closure of the glottis and (2) the aryepiglottic closure ("laryngealization"), the constriction of the aryepiglottic sphincter (aryepiglottic muscles, oblique arytenoid muscles, and the thyroepiglottic muscles). The argument was based on fiberoptic laryngoscope (24 frames parsec) observations that the aryepiglottic closure was made between the tubercle of the epiglottis, the cuneiform cartilages, and the arytenoid cartilages. The author argued that false vocal folds acted as a cushion for the tubercle of the epiglottis, instead of direct participants of the glottal constrictions. Stager et al. (2000) took Fischer-Jorgensen (1989)'s hypothetical view of glottal stops as associated with "a quick dampening of the vibration of the true vocal folds, resulting in a reduction of sound pressure level." Lastly, Umeda (1978) took an acoustic approach in defining glottal stops: (1) silence in the speech waves that is less than 100ms; (2) irregular vibration that occurs in the beginning of the vowel.

General patterns for glottal stop usage have been investigated in linguistics literature, including Umeda (1978). Umeda recruited 3 female and 2 male speakers to read four short stories that contain approximately 30 sentences. Each story varied from the others in terms of the content density, vocabulary type (rare vs. common) and the kind of discourse. First, they read the sentences in randomized order (list), than in the original order (story). A visicorder and a spectrogram were used to record the speech and determine the existence of a glottal stop.

The incidence of glottal stops highly varied among the speakers (25% to 80%).The only consistent pattern was that speakers chose to pause rather than produce glottal stops when reading the list version than the story version. When all speakers were pooled together, the percent occurrence of glottal stops was highest in the content words with primary stress on their initial syllables (50%), followed by content words with secondary stress on the initial syllables (30%), and then by function words that were preceded by grammatical boundary (20%). When the passage included higher content/function ratio and a higher number of rare words starting with vowels, the incidence of glottal stops increased. Finally, while phonological and grammatical differences were statistically insignificant compared to others, increased incidence of glottal stops was observed when function words were preceded by a grammatical break, such as phrase boundary or an interruption (e.g. however, instead). Umeda (1978) emphasized that glottal stops can serve as a boundary marker just as pauses do.

We are starting to understand from the results of Stager et al (2000, 2002) that certain linguistic contexts, such as phrases with serial vowel-initial words (e.g. "We eat eels every day.") might be accompanied by supraglottic activity in healthy speakers. However, further research is needed to determine additional linguistic contexts to more fully understand the role of these structures in normal speech production.

Whether glottal stops are specifically related to the FVF activity is yet to be investigated. Stager et al. (2000) found a relatively high incidence of dynamic FVF compression in tasks with glottal stops, but the tasks were limited to syllable and simple sentence level, such as repeated /i/, /isi/ and "We eat eels every day." Furthermore, it is unknown whether the dynamic supraglottic activity is related to linguistic characteristics associated with glottal stops, such as vowel-initial or /t/-final words and phrase boundaries. Therefore, the pattern of normal dynamic supraglottic activity needs to be investigated in these linguistic contexts associated with the glottal stops for the purpose of further differentiating normal supraglottic activity from the pathological.

In conclusion, the FVF hyperactivity can occur in various voice disorders, whether hyperfunctional (e.g. spasmodic) and hypofunctional (e.g. vocal fold paralysis) disorder. On the other hand, the presence of FVF itself is favorable to TVF lubrication and vocal resonance. Its activity, if not hyperfunctional, might aid in increasing sound intensity. Specifically, dynamic FVF compression might be integral to producing glottal stops at least at the phrase level. Therefore, the purpose of this study is to test the following hypothesis. First, it is hypothesized that one would observe the high incidence (>50%) of dynamic supraglottic activity at the location where glottal stops are aurally perceived even in sentence and paragraph-level as it was observed in "we eat eels every day" sentence in Stager et al. (2002). If this first hypothesis true, it is predicted that the incidence of dynamic supraglottic activity would also be directly associated with word-initial vowels, an allophone of voiceless stops, boundaries between voiced sounds, and the phrase boundaries, where glottal stops were observed to be most frequent. Stager

(2011) argued that we must identify the occurrences or quantitative degree of FVF compression in unusual phonetic contexts, in order to identify what is indicative of hyperfunctional voice disorder. Thus, this investigation into supraglottic compressions at phonetic and linguistic contexts listed above would assist the clinician in accurately differentiating the normal pattern of FVF activity from pathological ones at sentence and paragraph level.

# METHODOLOGY

## Subjects

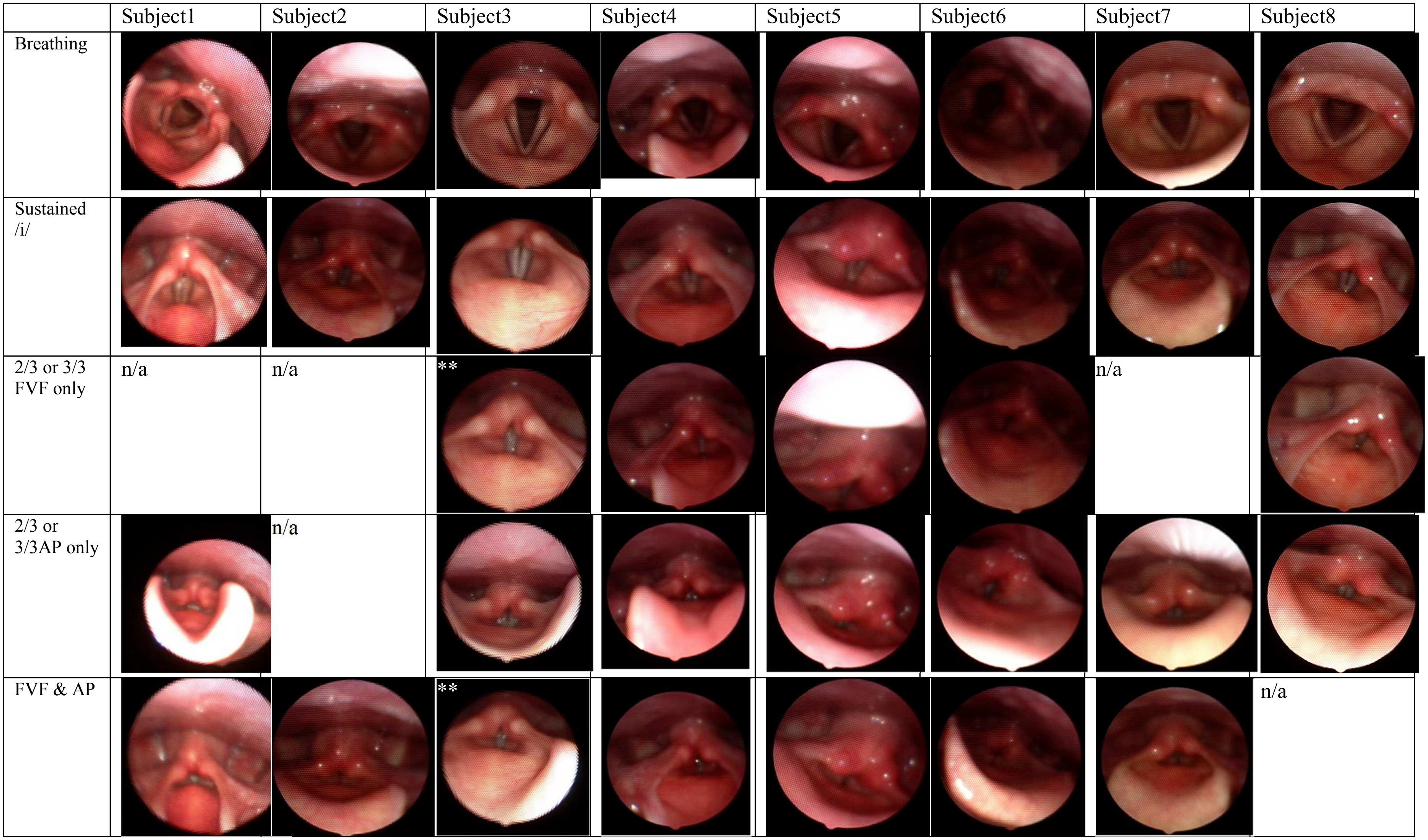
Nine subjects (2 M; 7 F) were initially screened for the study. The age ranged from 22 to 35 years old with an average of 25 years. The subjects' criteria to be included in the study were similar to those in Stager et al. (2002): a native speaker of American English, no history of voice disorder, no history of gastro-esophageal reflux disorder, as evidenced by frequent heartburn or acid indigestion, absence of respiratory disease/infection including asthma, no symptoms of laryngopharyngeal reflux (excessive coughing or excessive pharyngeal mucus), and no history of smoking. While the absence of professional voice training was not considered as an exclusion criterion, all subjects but one had never received professional voice training. Informed consent was obtained from participants in accordance with the Institutional Review Board of the University of Iowa.

When the subjects met the aforementioned criteria, a speech scientist who was highly experienced with stroboscopy visualized the subjects' false and true vocal folds using the pediatric flexible nasendoscope. If the suspicion of membranous or postglottic lesions was raised, the subject was then asked to clear his or her throat. If any irregularity on the surface of the vocal folds still remained, the subject's vocal folds were visualized again under a rigid oral endoscope in order to confirm the presence of the lesion. One subject who had received professional voice training exhibited bilateral bumps on the medial edges of the vocal folds under flexible nasendocope. When he subsequently underwent a rigid oral endoscopic procedure, the bumps on the edges of the vocal folds turned out to be mobile mucus, and thus the subject was included in the study. Another subject who satisfied the criteria was excluded from the study because, during the nasendoscopic procedure, the view of the true and false vocal folds was blocked by the epiglottis during majority of the speech. The final number of subjects whose data were included in the study was 8 (2M; 6F), with ages ranging from 22 to 29 years with an average age of 23 years old.

**Procedures**

Subjects underwent a simultaneous voice recording and videostroboscopic examination using a trans-nasal flexible fiberoptic laryngoscope and a microphone mounted on the TOSHIBA 3CCD camera. Because lidocaine, a topical anesthetic agent used during standard clinical nasendoscopic procedure, was not used, two alternative strategies were applied to minimize subject's discomfort. First, a nasal spray containing 1% Phenlyephrine HCl was sprayed onto both nostrils beforehand in order to reduce nasal congestion and widen the nasal passage. Then, a pediatric flexible nasendoscope (PENTAX; FNL-7RP2) with 2.6 mm diameter, instead of an adult nasendoscope, was introduced into the nasal passage, in order to minimize the surface contact between the scope and the nasal turbinates. Images of adduction and abduction of true vocal folds and of FVF and A-P compressions were captured from the video while each subject was asked to breathe, sustain /i/ at comfortable pitch for 5 seconds, repeatedly produce /i/ (i.e. /i, i, i, i/) at comfortable pitch, and to produce the phrase "We eat eels every day." Video samples from these stimuli were set as a reference or "anchor points" to assist in accurate analysis of subsequent video images (**Figure1**).

**Figure1. Reference points collected in all subjects**. Images were taken during breathing, sustained/i/, repeated /i/, and recitation of “We eat eels every day.”     **Only 1/2 of TVF obstructed by FVF compression. They were considered as absent of FVF compressions



Afterwards, the video/audio samples were collected while the subjects read aloud the given lists of sentences: (1) complex/compound sentences with consonant-initial words after the phrase boundary; (2) complex/compound sentences with vowel-initial words after the phrase boundary; (3) sentences listing the vowel/voiceless consonant/voiced consonant-initial names of animals; (4) 20-word sentences with voiced consonant and vowel- initial words, or with voiceless consonant-initial words; (5) Count 80-90. These stimuli were given for the purpose of investigating the association between supraglottic activity, glottal stops, and certain linguistic markers (phrase boundary, consonant/vowel-initial word, and comma). Stimuli (3) were particularly set for investigating whether occurrence the glottal stop and supraglottic activity are more affected by the vowel-initial words or the comma (linguistic marker). The subjects were not notified of the nature of the sentences. The complete list of sentences and words are in **table 1.**

**Table 1. List of phrase and sentence stimuli**

| Nature of the stimuli | Words or sentences |
|---|---|
| List of vowel-initial words | Count 80-90 |
| Simple sentence with vowel-initial words | We eat eels every day |
| 20- word sentence with **voiced** consonant- and vowel-initial words | Early one morning a man and a woman were ambling along a one-mile lane running near Rainy Island Avenue. |
| 20-word sentence with **voiceless** consonant-initial words | He saw half a shape mystically cross fifty or sixty steps in front of his sister Kathy's house. |
| Complex sentences with **consonant-initial word** after the phrase boundary (comma in place to signal the phrase boundary) | Paul woke up late, so he ran to catch the school bus.<br>Since Iowa City became cold, Paul has been wearing new gloves and a coat.<br>Although I wished to eat an orange, my uncle gave me an apple.<br>If you come home early, we will watch a movie. |
| Complex/compound sentences with **vowel-initial word** after the phrase boundary (comma in place to signal the phrase boundary) | Eric and I went to the park, and we played volleyball.<br>After Ellen was finished with her work, Ellen cleaned her house |
| Complex/compound sentence with consonant-initial word after the phrase boundary (**comma absent** at the phrase boundary) | Olivia went to bed early because she had to wake up at 6 am next morning<br>People like her for she speaks so pleasingly.<br>Paul has been wearing new gloves and a coat since Iowa City became cold. |
| Complex/compound sentence with vowel-initial word after the phrase boundary (comma absent at the phrase boundary) | My uncle gave me an apple although I wished to eat an orange<br>Ellen cleaned hear house after she was finished with her work.<br>We will watch a movie if you come home early. |
| Sentence with a list of animals<br>(a). vowel-initial name of animals<br>(b). voiceless consonant-initial name<br>(c).voiced consonant-initial name<br>*to investigate the **effect of punctuation marks and vowel-initial words** on the occurrence of glottal stop and supraglottic activity) | (a) I want to observe the following animals: ostrich, iguana, and elephant.<br>(b) Kathy wants to see the following animals: seal, tiger, and flamingo.<br>(c). George wants to observe the following animals: zebra, dolphin, and lion. |

**Data Analysis**

First, a graduate Speech-Pathology student and the author each conducted a perceptual auditory analysis only based on the audio signal. Prior to the analysis, the graduate student was informed of the characteristics of glottal stops: brief (less than 100ms) cessation of airflow and the acoustic output; glottal stops can be used as an allophone for "t" in words such as "mountain" or be inserted between a final vowel sound in a word and the next word that also begins with a vowel. (Umeda, 1978; Stager et al., 2000). Then, the student underwent a 15 minute auditory training session for distinguishing presence and absence of pause and glottal stops in a few selected speech samples collected in a previous pilot study and live speech samples produced by the author who purposely produced glottal stops at certain words.

The author and the fellow student independently rated the speech sample of all subjects, circling the location where they perceptually heard the glottal stop. They were each allowed to review the audio samples as many times as necessary. Only the locations where both judges perceived glottal stops were considered as those with glottal stops present.

Next, the author reviewed the accompanying video segments of the sample in slow motion. For each speech task (one sentence unit as one speech task), the nature of FVF compression and A-P compression activity was rated qualitatively based on modified categories from Stager et al. (2001, 2002)(**Table 2**). The videos were first set into mute in order to prevent the auditory signal from biasing the visual ratings of the supraglottic activity. Once the presence of the supraglottic activity was detected, the audio was turned back on at that location to help find the syllable of the word where supraglottic activity was judged to be present.

**Table 2. Categorical ratings for video image analysis**

| | |
|---|---|
| ***FVF compression***: Medial adduction of the false vocal folds (Stager et al., 2002) | ***A-P compression***: The arytenoid cartilages approaching the petiole of the epiglottis (Stager et al., 2002) |
| ***NO-FVF***: no visual obstruction of the TVF by FVF during the speech task | ***NO A-P*** : no visual obstruction of the true vocal folds by apposition of the arytenoid cartilages and petiole of the epiglottis during the speech task |
| ***STATIC-FVF***: 2/3 to 3/3 visual coverage of the TVF by the FVF that lasts more than .2* seconds | ***STATIC A-P***: 2/3 to 3/3 visual coverage of the TVF by arytenoid-to-petiole apposition that lasts more than .2 seconds |
| ***DYNAMIC FVF*** : 2/3 to 3/3 visual coverage of the TVF by brief single adductions of the FVF (≤ .2 sec) | ***DYNAMIC A-P***: 2/3 to 3/3 visual coverage of the TVF by brief single appositions of the arytenoid and petiole (≤ .2 sec) |

*Average duration of one syllable (Yang, 1998)

Although Stager et al. (2001) considered 1/3 visual coverage of the TVF as the presence of supraglottic activity, 1/3 coverage was difficult to be differentiated from no visual obstruction using the images collected with pediatric scope. Therefore, only 2/3 and 3/3 visual coverage of the TVF were considered as the definite presence of supraglottic activity. In addition, while

Stager et al.(2001) named a compression as static only when it lasts the entire speech task, their speech task only included prolonged or repeated syllables and simple 3-6 word sentence, which were much shorter in duration than the speech task in the present analysis. Thus, static activity was defined to be the compression that lasts more than 0.2 seconds.

The syllables of the words during which dynamic FVF and A-P compression occurred were compared to the perceptual analysis to investigate whether the occurrence of glottal stops and dynamic supraglottic activity matched in time.

Finally, inter-judge reliability was computed for perceptual analysis while intra-judge reliability was computed for video analysis. The intra-judge reliability was measured by repeating videos analysis with three sentences from every subject.

## RESULTS

The results are organized to address the specific questions identified in the introduction.

**Incidence of glottal stops**. Two judges independently rated the presence or absence of glottal stops within each word within the set of stimuli for all subjects, using only auditory signals. Only the words where both judge agreed on the presence of glottal stops were to be considered as those with glottal stops. The proportion of exact agreement between judges was 89% (1693 words rated in consensus/1904 total words).

The average incidence of words perceived with glottal stops on the sentence list across all subjects was 19% (standard deviation ±4.2%), ranging from 11 to 24% (**Table 3**).

**Table 3**. **Number of aurally perceived glottal stops that were in exact agreement between two judges.** Percentages were calculated by the number of glottal stops in consensus divided by total number of words in the stimuli (238 words).

| | Number of glottal stops in consensus | % (total=238 words) |
|---|---|---|
| subject1 | 25 | 11 |
| subject2 | 43 | 18 |
| subject3 | 39 | 16 |
| subject4 | 44 | 19 |
| subject5 | 55 | 23 |
| subject6 | 49 | 21 |
| subject7 | 57 | 24 |
| subject8 | 50 | 21 |
| Average | 45 | 19 |
| Std. Dev | 10.2 | 4.19 |

**Supraglottic activity associated with glottal stops**. The author who conducted a video image analysis re-rated the presence or absence of FVF and A-P compressions within three sentences collected from all eight subjects. The proportion of exact agreement of the ratings of supraglottic activity at the initial phoneme of the words t was 85% (231words categorized in agreement/ total 272 words).

In regards to the first hypothesis, there was a high association between supraglottic activity and glottal stops, as 72% (SD±13%) of the total words were judged to be produced with glottal stops showed either FVF or A-P compressions, with 30% of total words exhibiting FVF compressions and 70% of total exhibiting A-P compressions. The most frequent type of compressions during glottal stop was dynamic A-P compression only (25%), followed by dynamic FVF compression in conjunction with dynamic A-P compression (22%) (**Table 4**). On the other hand, the incidence of dynamic FVF compression only was low (2%), while static FVF compression was virtually absent in all subjects.

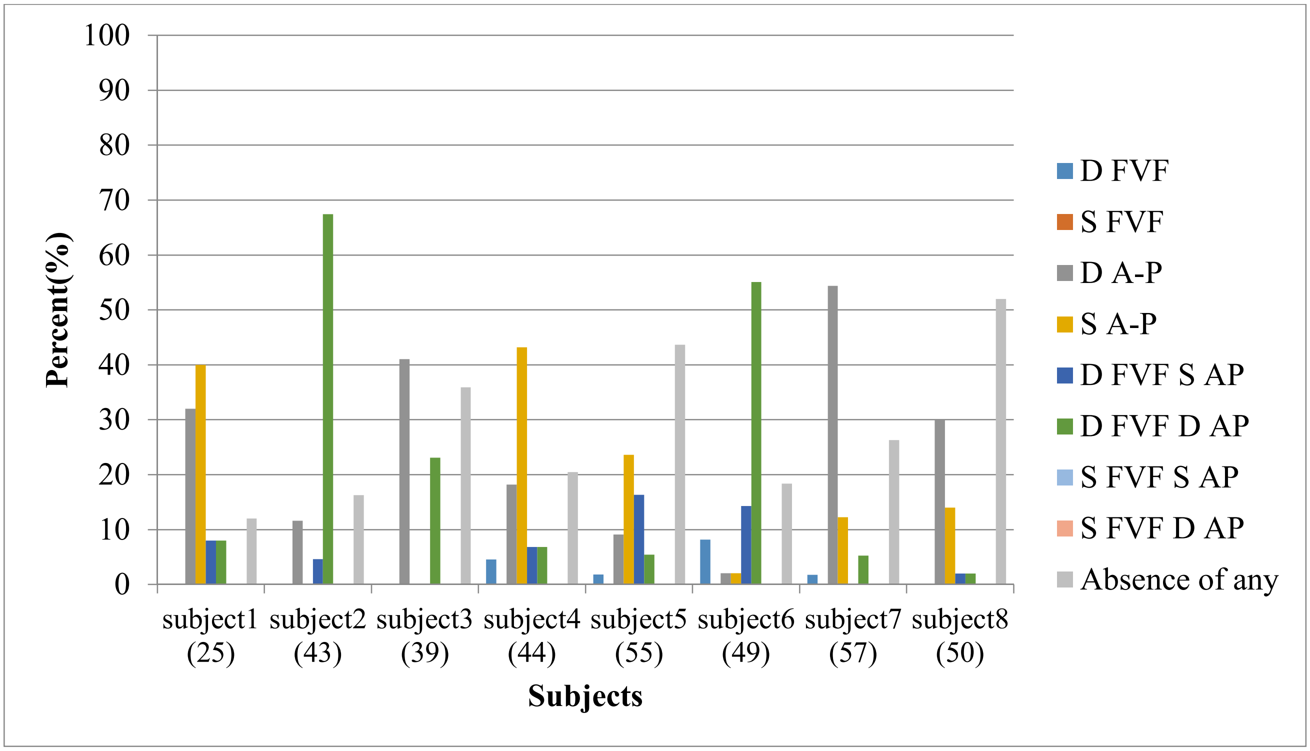
**Table 4. Average incidence of FVF/AP compressions (%) at aurally perceived glottal stops, listed from most common to least common.**

| Activity | % (out of total words with glottal stops) | Standard Deviation |
|---|---|---|
| **D AP alone** | 24. 8 | 17.7 |
| **DFVF w/ D AP** | 21.6 | 25.5 |
| **S AP alone** | 16.9 | 17.3 |
| **D FVF w/ S AP** | 6.5 | 6.2 |
| **D FVF alone** | 2.0 | 2.8 |
| **S FVF** | 0 | 0 |
| **Average Total** | 71.9 | |

Individual subjects did not always show the pattern indicated by the average values. As shown in Figure 2, subjects tended to have one pattern of supraglottic activity that was used with much greater incidence than the other patterns. For example, subject 2 produced dynamic FVF compressions in conjunction with dynamic AP compressions in 67% of the words with aurally perceived glottal stops whereas subject 7 produced them in only 5% of the words. Instead, subject 7 produced dynamic AP compressions only in 54% of the words. On the other hand, subject 4 produced static AP compressions only (43%) at maximum incidence at words perceived with glottal stops. at This result suggests each speaker has different preferences for the type of supraglottic activity they produce during words with glottal stops. While the incidence of dynamic FVF compression may exceed 70% for one, it may only stay at 4% for another.

However, it was clear across the subjects that dynamic FVF compressions are more likely to occur in conjunction with AP compressions rather than being produced alone

**Figure 2**. **Incidence (%) of FVF and AP compressions rated at aurally perceived glottal stops.** The number in parenthesis of the horizontal column is the number of aurally perceived glottal stops produced by each subject. Incidence of static FVF compression was 0%, so is absent in the graph.

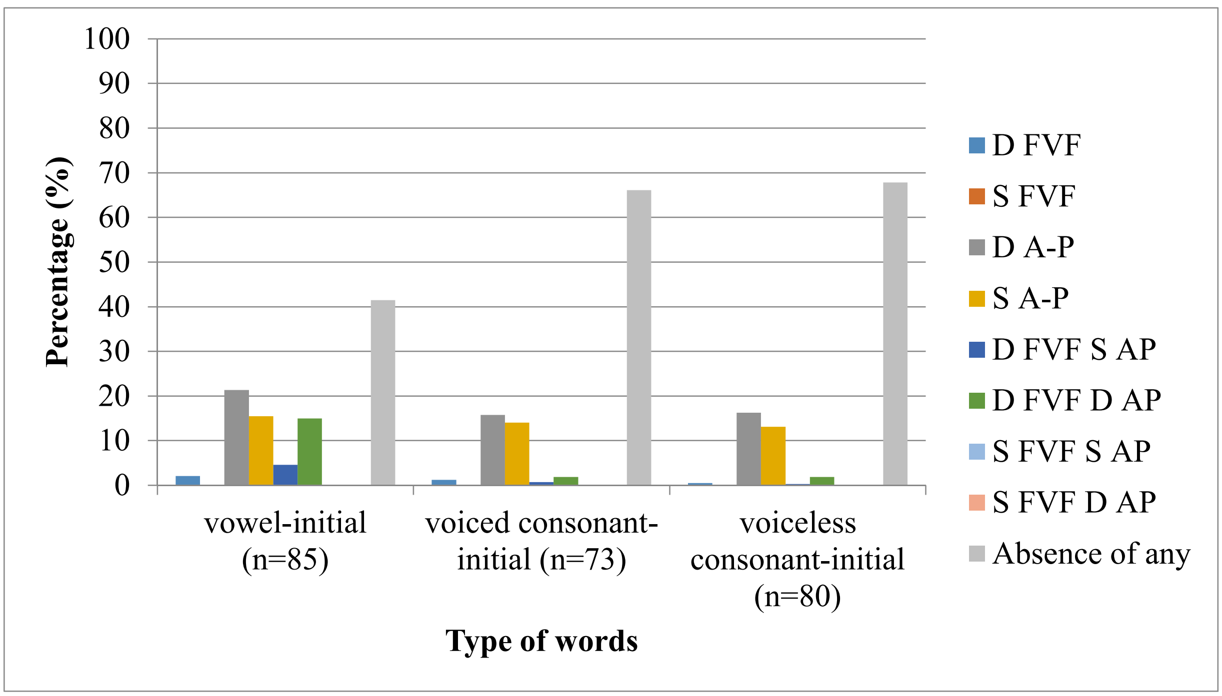



**Footnote: D FVF means dynamic false vocal fold compressions. S FVF means static false vocal fold compressions. AP indicates anterior-posterior compressions.**

**Comparison of vowel-initial words and consonant-initial words.** The FVF and A-P compression activities were compared between the vowel-initial words, voiceless consonant-initial words within the set of sentences, and voiced consonant initial words (**Figure 3**). The incidence of supraglottic activity was the greatest at vowel-initial words(59%) followed by voiced consonant-initial (34%) and voiceless consonant-initial words (32%).The incidence of FVF compressions at the first phoneme of vowel-initial words (22%)  were more frequent than those at the first phoneme of voiced consonant(4%) and voiceless consonant- initial words (3%). The incidence of A-P compressions at the first phoneme of vowel-initial words (56%) was also more frequent than those at the first phoneme of voiced consonant (33%) and voiceless consonant- initial words (32%).

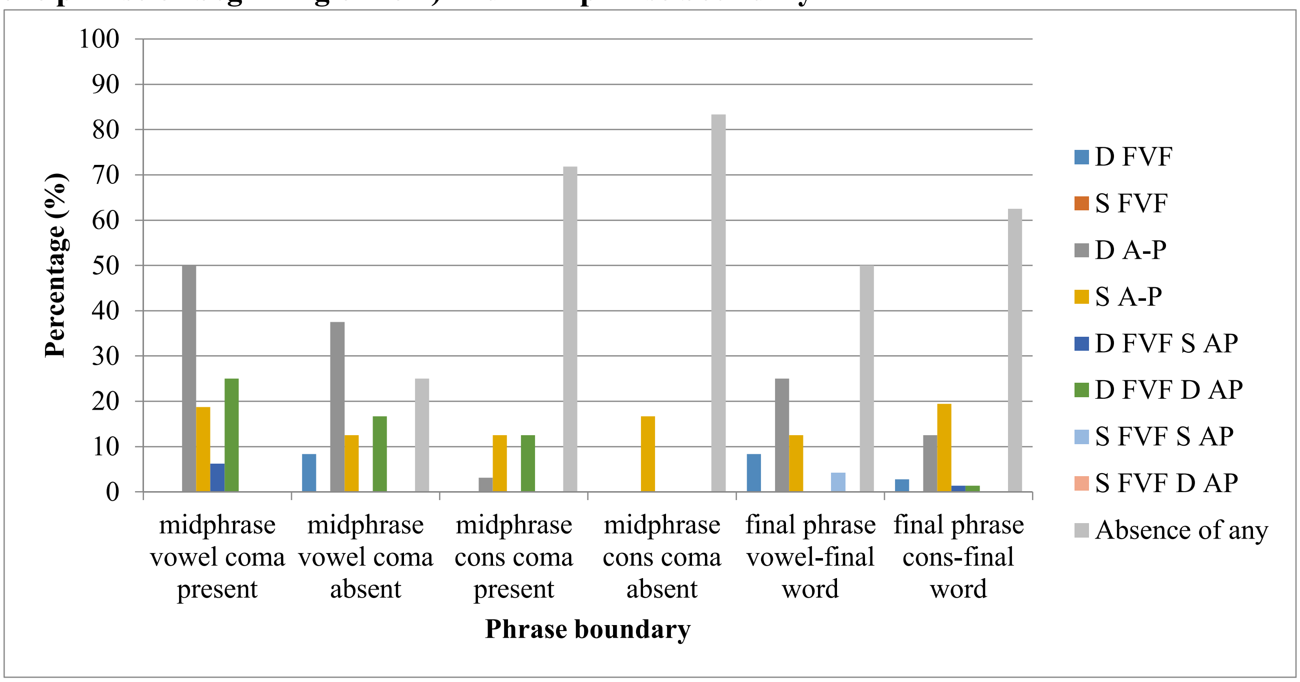
More specifically, the incidence of dynamic FVF compression in conjunction with dynamic A-P (D FVF & D AP) compression at the first phoneme of vowel-initial words (15%) was significantly higher ($p$=0.02) than much the other two contexts, which both were at 2%. The incidence of dynamic FVF compression in conjunction with static A-P compression (D FVF & S AP) at vowel-initial words (4.6%) was also significantly higher ($p$=0.02) than the other two contexts which were 0.7% and 0.3% respectively. No significant group differences were found in incidence of six other types of activities.

**Figure 3. Average incidence (%) of FVF/AP compressions at consonant vs. vowel-initial word**




**The incidence of supraglottic activities at phrase boundaries**. High subject-to-subject variability was observed again, yet average incidence of supraglottic activity at mid-phrase and final phrase boundary revealed general patterns across the subjects (**Figure 4**). The average incidence of supraglottic activity was the highest when a coma was present in the mid-phrase as the phrase boundary was followed by a coma and a vowel-initial word and showed 100% incidence. If the coma was absent, the average incidence went down to 75%. The average incidences of FVF or AP compressions at final phrase boundaries ending with vowel-final words and that with consonant-final words were 50% and 48% respectively. The average incidences of FVF or AP compressions at mid-phrase boundary followed by a consonant-initial word was the lowest of all conditions, with 28% incidence when coma was present and 17% when coma was absent. Both mid- and final-phrase boundary showed higher incidence of supraglottic activity when it was either followed by a vowel-initial word or ends with vowel-final word.

**Figure 4**. **Average incidence (%) of FVF/AP compression at mid phrase boundary (either end of one phrase or beginning of next) and final phrase boundary**

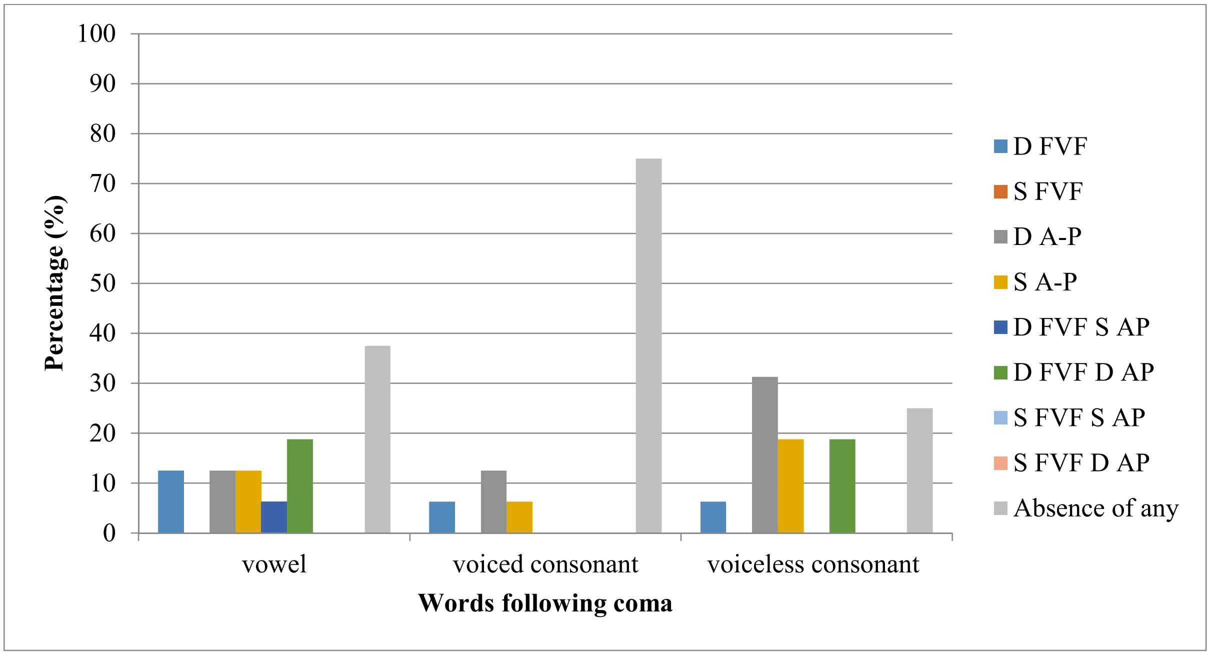



More specifically, dynamic A-P compression showed markedly increased incidence(75%) at mid-phrase boundary followed by a vowel-initial word, of which 1/3 of time it was present in conjunction with dynamic FVF compression. The dynamic AP compression showed higher incidence when the mid-phrase boundary was followed by a vowel word vs. a consonant-initial word and when a coma was present in the mid-phrase boundary. Same pattern was observed with dynamic FVF compression although its average incidence was generally lower than both dynamic AP compressions. All dynamic FVF compression occurred in conjunction with either static or dynamic AP compression at mid-phrase boundary followed by a vowel initial word. On the other hand, final phrase boundary ending with vowel-final word, all FVF compressions occurred alone.

Static AP compression was also highest in incidence at the mid-phrase boundary followed by a vowel-initial word. However, at final phrase boundary, the pattern was reversed where a consonant-final word yielded a higher static AP compression than a vowel-final word. Static FVF compression was virtually absent except at final phrase boundary ending with vowel-final word.

**Impact of punctuation**. In order to measure whether vowel-initial words or a punctuation marks such as coma impact the incidence of supraglottic activity, we used three "animal" sentences which contain vowel, voiced consonant, or voiceless consonant initial animal words are followed by a ":" or by a coma. If punctuation marks take more of a leading role in increasing the supraglottic activity than the phonemic nature of the word, one will see comparable incidence of supraglottic activities across the three contexts. However, the frequencies were markedly different with 75% for an "animal" sentence with voiceless consonant, 63% for that with vowel and 25% for that with voiced consonant-initial words (**Figure 5**). Incidences of dynamic FVF compression only (12.5%) and of dynamic FVF compression in conjunction with static AP compression (6.5%) were highest for the sentence with vowel-initial "animal" word. On the other hand, the incidence of dynamic FVF compression in conjunction with dynamic AP compression was equal between the vowel-initial (19%) and the voiceless consonant-initial (19%) group. Furthermore, dynamic or static AP compressions were more frequent in the voiceless consonant-initial group (31%; 19%) than in the vowel-initial group (13%; 13%).

**Figure 5. Average incidence (%) of FVF/AP compression within "animal" sentence on locations where : or , are placed, followed by vowel/voiced consonant/voiceless consonant-initial words (n=3)**




**/t/-final words**. It has been proposed by Umeda (1978) that glottal stops may be present as an allophone of /t/ in a /t/-final word, especially when it is followed by a vowel. With assumption of Umeda (1978)'s argument to be true, the hypothesis of increased incidence of supraglottic activity at /t/-final words was tested. /t/ final words occur 11 times in the set of stimuli, of which not all words were followed by a vowel-initial word. Subject variability was again shown where, for instance, subject 3 hardly produced any supraglottic activity while subject 4 produced supraglottic activity 73% of the time (**Figure 6**). Also the type of most frequent type of supraglottic activity varied from subject to subject as subject 2 showed dynamic FVF-dynamic AP activity 36% of the time and never produced static A-P activity while subject 2 showed static A-P only activity 55% of the time. The average incidences of FVF or A-P compressions across subjects at /t/ final words was high at 68%, with the incidence of FVF compression at 23% and that of A-P compression at 41% (**Table 5**). The incidence of static AP compression and dynamic FVF compression was highest of all at 23%. Majority of dynamic FVF compressions, though, was in conjunction with dynamic A-P compressions. The next high incidence of compression was dynamic A-P compression (22%).Considering that at aurally perceived glottal stops the average incidence of dynamic FVF compression or of dynamic AP compression was 30.2% and 46% respectively, the incidence of dynamic FVF and AP compression at /t/-final words were lower.

**Figure 6. Incidence (%) of supraglottic activity at /t/-final words for each subject**

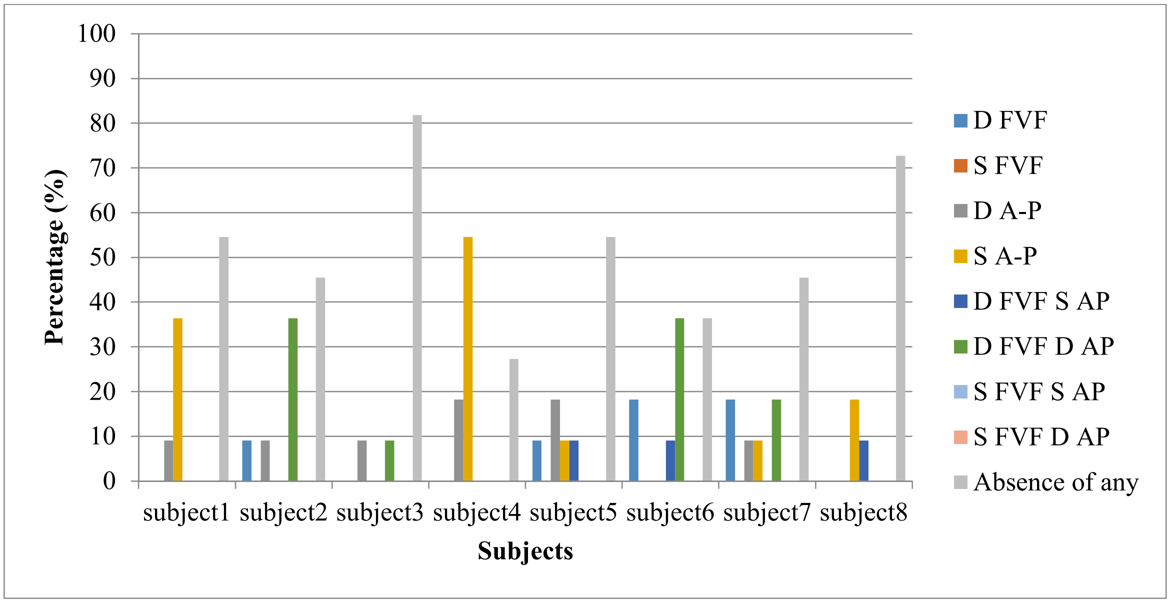



**Figure 7a.** 2/3 FVF compression at unreleased "t" at the word "late" in subject5, in comparison to the picture with absence of supraglottic activity

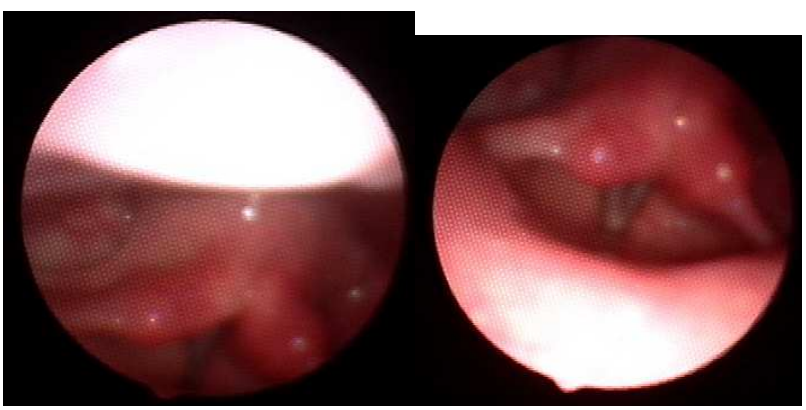


**Figure 7b.**3/3 FVF compression at unreleased "t" at the word "eighty-eight" in subject6, in comparison to the picture with absence of supraglottic activity

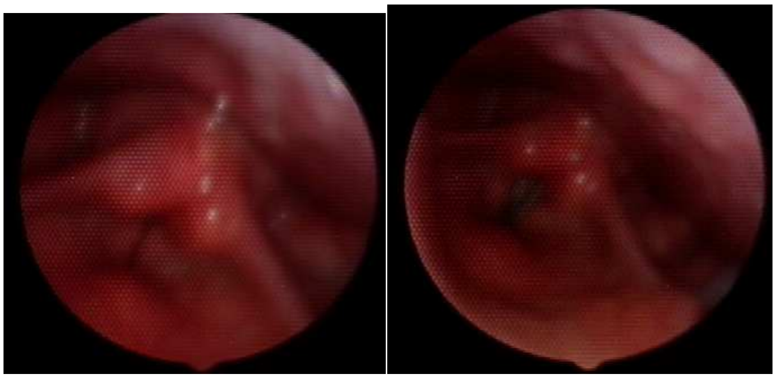


**Table 5. Average incidence (%) of supraglottic activity at /t/-final words across subjects listed from most common to least common**

| Activity | % (out of total /t/-final words) | Standard Deviation |
|---|---|---|
| **S AP alone** | 15.9 | 18.6 |
| **DFVF w/ D AP** | 12.5 | 15.0 |
| **D AP alone** | 9.1 | 6.4 |
| **D FVF alone** | 6.8 | 7.5 |
| **D FVF w/ S AP** | 3.4 | 4.4 |
| **S FVF** | 0 | 0 |
| **Average Total** | 47.7 | |

**Maximum supraglottic activity**. Because high subject variability was revealed in every analysis, the types of phonemes where true vocal folds were completely occluded by FVF or AP compression (i.e. 3/3 compression) were laid out to further understand the idiosyncratic pattern of maximum supraglottic compressions in every subject. While subject 2 and 6 produced both 3/3 FVF compression, rest of the subjects except subject 9 produced only 3/3 AP compression. As FVF and AP compressions were most frequently observed in vowel-initial words, most of the 3/3 compressions were also observed at vowels, especially the front vowels (e.g. i, eI, ɛ, æ, a:I). On the other hand, 3/3 FVF or AP compressions were observed at /t/ across three subjects. Subject 1 produced 3/3 AP compression at not only /t/ but also a wide variety of other phonemes (b, g, k , f, dʒ, ng) where glottal stops may be more unlikely. Some of them were palatal and velar consonants as expected by Stager et al. (2002).

**Table 6. List of phonemes where 3/3 FVF or AP compressions were observed**

| | **phonemes where 3/3 compression was observed** | |
|---|---|---|
| | FVF | AP |
| **subject1** | | æ, b, a:I, ɛ, dʒ, k, ng, I t, g, f, e:I, i |
| **subject2** | i, ɛ, ʌ, eI, t, n, æ | æ, eI |
| **subject3** | | a:I, ɛ, æ, h |
| **subject4** | | ɛ, p, o, t |
| **subject5** | | ɛ |
| **subject6** | i,ɛ, æ, I, m, o , ɚ, ə, e:I, t | |
| **subject7** | | a:I |
| **subject8** | n/a | n/a |

**Pattern of dynamic supraglottic activity.** In contrast to the hypothesis, the average incidence of dynamic FVF compressions at aurally perceived glottal stops was 30.2%, which was below 50% (**Table 7**). Most of these compressions occurred in conjunction with dynamic (21.6%) or static (6.51%) AP compressions. Only 2.04% out of the total number of words with glottal stops was accompanied by dynamic FVF compressions alone. Nevertheless, the incidence of dynamic FVF compressions at locations of glottal stops was higher than that of dynamic FVF compressions measured at other linguistic contexts that are associated with glottal stops except at mid-phrase boundary followed by vowel-initial words. Furthermore, similar to the FVF compressions predominantly dynamic in Stager et al. (2000), the present study revealed FVF compressions at glottal stops to be dynamic (30.2%) more so than static (0%).

**Table 7. Average incidence (%) of dynamic FVF compressions at different contexts**

| Contexts | Average incidence of dynamic FVF compressions(%) |
|---|---|
| At aurally perceived glottal stops (n= avg.45) | 30.2 |
| At vowel-initial words (n=85) | 21.6 |
| At voiced consonant-initial words (n=73) | 3.8 |
| At voiceless consonant-initial words (n=80) | 2.7 |
| At mid-phrase boundary followed by vowel-initial words. Coma present (n=2) | 31.3 |
| At mid-phrase boundary followed by vowel-initial words. Coma absent (n=3) | 25.0 |
| At mid-phrase boundary followed by consonant-initial words Coma present (n=4) | 12.5 |
| At mid-phrase boundary followed by consonant initial words. Coma absent (n=3) | 0.0 |
| At final phrase boundary ending with a vowel-final word (n=3) | 8.3 |
| At final phrase boundary ending with a consonant-final word (n=9) | 5.6 |
| At /t/-final words (n=11) | 22.7 |

The average incidence of all AP compressions (**Table 8**) at aurally perceived glottal stops was 70%, which was much more common than 44~51% of incidence observed in Stager et al. (2002). In fact, subject 7 and 8 were more likely use static or dynamic AP compressions only when they produced glottal stops. The average incidence of dynamic AP compressions (46%) was higher than the incidence of static AP compressions (23%). However, individual variability was also noted in AP compressions as subject 4 would show higher incidence of static AP compressions while subject 7 showed much higher incidence of dynamic AP compressions.

**Table 8. Average incidence (%) of dynamic AP compressions at different contexts**

| Contexts | Average incidence of dynamic AP compressions (%) |
|---|---|
| At aurally perceived glottal stops (n= avg.45) | 46.4 |
| At vowel-initial words (n=85) | 36.3 |
| At voiced consonant-initial words (n=73) | 17.8 |
| At voiceless consonant-initial words (n=80) | 18.1 |
| At mid-phrase boundary followed by vowel-initial words. Coma present (n=2) | 25.0 |
| At mid-phrase boundary followed by vowel-initial words. Coma absent (n=3) | 12.5 |
| At mid-phrase boundary followed by consonant-initial words Coma present (n=4) | 12.5 |
| At mid-phrase boundary followed by consonant initial words. Coma absent (n=3) | 16.7 |
| At final phrase boundary ending with a vowel-final word (n=3) | 16.7 |
| At final phrase boundary ending with a consonant-final word (n=9) | 20.8 |
| At /t/-final words (n=11) | 21.6 |

The second hypothesis was that dynamic FVF compressions were expected to occur at high percentage (>50%) at linguistic contexts associated with higher incidence of glottal stops, which include vowel-initial words, final /t/ words, and mid- and final- phrase boundaries. It was expected that when phrase boundaries are specifically marked with linguistic markers such as a coma or a colon, dynamic FVF compressions would more likely occur.

The incidences of dynamic FVF compressions in conjunction with AP compressions (D FVF-D AP; D FVF-S AP) at vowel-initial words were significantly ($p<0.05$) greater than those at voiced or voiceless consonant-initial words. Such differences were not found in incidence of dynamic FVF alone or static/dynamic AP compressions alone.

When comparing various mid- and final- phrase boundary groups, the mid-phrase boundary followed by a coma and a vowel-initial word revealed highest incidence of dynamic FVF compressions (31.3%) as expected. In fact, the average incidence was much higher than the incidence of dynamic FVF compressions at all vowel-initial words (22%), and was slightly greater than that at aurally perceived glottal stops (30.2%). When a coma was absent, the average incidence of dynamic FVF compression at mid-phrase boundary went down to 25%. Incidence of dynamic FVF compressions was much lower at mid phrase boundaries followed by consonant-initial words. If the coma was present, the average incidence was 12.5%, but if the coma was absent, the average incidence went down to 0%. The similar pattern of average incidence for dynamic AP compressions was revealed as the incidence was more likely to be higher if the phrase boundary was followed by a vowel-initial word, and if it was marked with a coma (VCP=75%,; VCA=54%; CCP=16%; CCA=0%). The ranks in the incidence of dynamic FVF and dynamic AP compressions were each comparable to the average incidence of aurally perceived glottal stops at mid-phrase boundaries (VCP=69%; VCA=54%; CCP= 0%; CCA=0%). This suggests that both dynamic FVF compressions and dynamic AP compressions are elevated at mid phrase boundary in a condition that it is marked with a coma and is followed by a vowel-initial word.

# DISCUSSION

This study attempts to describe the relationship between the supraglottic activity and glottal stops and their related linguistic contexts. Contrary to the previous beliefs that the presence of supraglottic activity indicates hyperfunctional voice disorders, Stager et al. (2000) found within the control group (allergic symptoms present but no dysphonia) that FVF compressions were present in 52% of the speech tasks where a large number of glottal stops were produced. These FVF compressions were predominantly dynamic, which were defined as a rapid movement of supraglottic structure that lasts only a part of the speech task. Stager et al. (2002) repeated the study on healthy subjects only, and found dynamic FVF compressions to be present over 90% of the same speech tasks (e.g. repeated /i/, repeated /i-si/, "We eat eels every day" sentence). On the other hand, during speech tasks which involved either sustained phonation or voiceless consonant initial words, the average percent occurrence of FVF compression went down to 17%. Because Stager et al. (2000) only examined the supraglottic activity at single word or phrase level, this study investigated whether similar pattern would occur at the level of complex or compound sentences as they more closely resemble the conversational speech. It was first hypothesized that dynamic FVF compressions would occur at least 50% of the time at locations where glottal stops were aurally perceived.

The incidence of dynamic FVF compressions at glottal stops, along with other types of supraglottic activity, varied highly from subject to subject. As Umeda (1978) observed highly variant frequencies and patterns of glottal stops between speakers who read a given passage, the dominant type of supraglottic activity at words perceived with glottal stops are highly variant from subject to subject. Whether this phenomenon is due to anatomical and neurological differences or acquired speech habits is still unknown. The lower FVF compression incidence than expected at aurally perceived glottal stops might indicate weaker direct association between dynamic FVF activity and aurally perceived glottal stops than expected. However, another explanation for lower incidence exists. This study did not take 1/3 to 1/2 FVF compressions into account, which could have underrepresented the actual incidence of the FVF activity.

Despite the lower incidence of FVF compression at glottal stops, this study revealed that incidence of dynamic FVF compressions are still relatively elevated at vowel-initial words, and at phrase boundaries followed by a vowel-initial word and a coma, which are known to be associated with high incidence of glottal stops (1978). However, the nature of the phonemes that make up the word seemed to more strongly impact the incidence of FVF than the placement of punctuation or the phrase boundary. This was evidenced by the high incidence of supraglottic activity at phrase boundaries followed by vowel-initial words (31.3%) compared to phrase boundaries within different contexts. If the phrase boundary was followed by a consonant word, the incidence was low despite the presence of a comma (12.5%).

The general order of maximum to minimum incidence of dynamic FVF compressions were vowel-initial, voiced consonant-initial, and lastly voiceless consonant-initial, yet the "animal" sentences interestingly revealed a different pattern: While dynamic FVF compressions (25%) were still less frequent than in vowel-initial "animal" words (38%), they were higher than in voiced consonant-initial words (6%). Moreover, its dynamic AP compressions (50%) at voiceless consonant-initial words in "animal" sentence exceeded those at vowel-initial words (38%) in incidence. This unusual pattern might be explained by the fact that one voiceless-consonant initial word in the "animal" sentence was "tiger," a /t/-initial word. In fact, two incidences of complete occlusion of TVF by FVF (3/3 occlusion) was observed at these /t/-initial words. Umeda (1978) argued that a greater number of glottal stops are observed at /t/-final words, especially when they are followed by a vowel. Based on this observation, we may be able to extend the argument to /t/-initial word, which may show elevated frequencies of dynamic FVF or AP compressions. Furthermore, dynamic FVF compressions showed increased incidence at /t/-final words (22.7%) on average, which were comparable to vowel-initial words (21.6%). Half of these compressions occurred in conjunction with dynamic AP compressions. This may solidify the direct relationship between dynamic FVF and AP compressions and glottal stops which are supposedly more frequent at vowel-initial and /t/-final words (Umeda, 1978).

As dynamic FVF compressions were frequent at vowel-initial and /t/-final words, 3/3 FVF compressions, with TVF being completely occluded by FVF, were present at vowels and /t/ within subject 2 and 6. However, these two subjects also showed complete occlusions at unexpected phonemes such as nasals (e.g. /n/, /m/). 3/3 AP compressions were more widely observed across all subjects, and included wider variety of phonemes, including fricatives, nasals, plosives etc. Some phonemes were velar and palatal consonants (Stager et al. 2002) as expected, but other included more labial consonants, such as /b/, /f/. This primitive finding suggests that the degree of dynamic compressions might show a different associative pattern with linguistic and phonemic contexts, than the incidence of dynamic compressions, and it needs further investigation.

The high subject to subject variability of the normal supraglottic activity indicates that one should take idiosyncratic patterns into consideration before deciding the supraglottic activity to be pathologic. Also, when using a high load of vowel-initial word passage to diagnose the presence or absence of adductor spasmodic dysphonia, one should take into consideration that incidence of supraglottic activity will rise even in normal subjects.

There are a few limitative factors to the accurate results in the study. Only eight subjects were included in the study, and they were all in their 20's or 30's. Subjects were also predominantly females. The subjects with narrow age ranges and skewed age ratio might not have well represented general healthy adult population without dysphonia. Also, a pediatric scope used in the study had a smaller field of vision and lower number of pixels per image than an adult scope. Due to lower qualities of video, only the definitive supraglottic compressions, which occlude 2/3 to 3/3 of TVF, were taken into account for this study. 1/3 to 1/2 supraglottic compressions were considered as "absent," and this might have lowered the rated overall incidence of FVF compressions compared to those calculated in Stager et al. (2000, 2002) studies. Finally, only intra-judge reliability was measured for video analysis. Inter-judge reliability would have been more appropriate for more objective and reliable judgments.

For future investigations to compare the association between dynamic FVF and phrase vowel-initial words versus phrase boundary, it will be beneficial to increase the number of complex/compound sentence stimuli and also the types of vowel-initial words with vowels of various tongue placements. The sentence sets used in this study focused on the phonetic and linguistic contexts around the phrase boundary. Thus, in order to more accurately compare the relationship between FVF activity and vowel, voiced consonant and voiceless consonant-initial words in the future, it is may be beneficial to include a phonetically balanced passage, such as a Rainbow passage. When these future studies take place, it may be beneficial to increase the number of repetitions each subject read the stimuli in order to investigate the degree of consistency of glottal stops and supraglottic activity. Also, one might compare the hard with soft glottal stops, and investigate how the strength or degree of the glottal stops is associated with the incidence or degree of the supraglottic activity.

In summary, despite the idiosyncratic patterns of supraglottic activity between subjects to subjects across all speech tasks, this study demonstrated elevated frequencies of dynamic FVF compressions at aurally perceived glottal stops, and at linguistic contexts that have been known to be associated with glottal stops, such as vowel-initial words, /t/-final words and phrase boundaries. Majority of these dynamic FVF compressions, though, occurred in conjunction with dynamic or static FVF compressions. High incidence of dynamic FVF compressions and dynamic AP compressions were observed at mid-phrase boundaries, only when the phrase boundary is followed by a coma or a colon and a vowel-initial word, suggesting that punctuation marks and the nature of the phonemes might play an important role in inducing dynamic supraglottic activity. Thus, the dynamic supraglottic activity is not only present in young, healthy adults, but also is more frequent at specific linguistic contexts, such as glottal stops and vowel-initial words. Also, complete occlusion of true vocal folds by supraglottic structures can be present at a wide variety of phonemes while this may also vary from subject to subject.

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