IN VIVO MODELING OF ACUTE EXTERNAL SUPERIOR LARYNGEAL NERVE DENERVATION USING LIDOCAINE BLOCK

by

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A thesis submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Master of Arts

in

Speech-Language Pathology

Department of Communication Sciences and Disorders

The University of Utah

August 2008

THE UNIVERSITY OF UTAH GRADUATE SCHOOL

SUPERVISORY COMMITTEE APPROVAL

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ABSTRACT

The external branch of the superior laryngeal nerve (ESLN) innervates the cricothyroid (CT) muscle of the larynx, a vocal fold tensor primarily responsible for pitch elevation. For over 100 years, a controversy has existed regarding the laryngeal signs that should be considered pathognomonic of unilateral ESLN paralysis. Regrettably, little progress has been made in resolving this controversy, as the extant clinical literature is characterized by contradiction and inconsistency. Myriad descriptions exist of the laryngeal behaviors ostensibly associated with unilateral ESLN denervation. To address this longstanding controversy and improve diagnostic precision, this preliminary investigation aimed to model "in vivo" acute, unilateral CT dysfunction by temporarily blocking the ESLN using lidocaine hydrochloride (HCL), and verifying selective denervation using laryngeal electromyography (LEMG). The purpose of this investigation was twofold: (1) to identify the salient laryngeal features associated with acute denervation (i.e., the pathognomonic features of unilateral CT dysfunction), and (2) to identify a set of laryngeal tasks that maximally provoke or reveal ESLN dysfunction, thereby contributing to a set of diagnostic tasks/markers that will improve diagnostic accuracy during clinical assessment.

Ten vocally normal adult males (mean age = 25 yrs.; range = 19 to 29 years) underwent lidocaine block of the right ESLN, and flexible videolaryngostroboscopic (FVLS) recordings were acquired before and during the block. Eleven blinded, expert judges (6 laryngologists and 5 Ph.D. speech-language pathologists) rated randomized, pre- vs. during-block recordings of 10 vocal tasks using standard FVLS rating protocols. Contrary to clinical reports, no evidence of hypomobility/sluggishness of the ipsilateral vocal fold, or a reliable pattern of axial rotation of the larynx during high pitch voice was observed. Furthermore, no evidence was observed to support reduced vocal fold longitudinal tension, aryepiglottic fold length asymmetry, phase asymmetry, vocal fold plane differences, or glottic insufficiency, as diagnostic features of unilateral CT dysfunction. Instead, the analysis revealed (1) a pattern of deviation of the petiole of the epiglottis to the side of weakness (i.e., the right) in 60% of participants during a glissando up maneuver produced at normal volume, and (2) a pattern of axial rotation of the posterior commissure to the left and the anterior commissure to right in 50% of participants during a maneuver which rapidly alternated between a maximum vocal fold abduction task (Sniff) and a high-pitched "ee" production. Both of these findings have not been previously reported elsewhere, and potentially represent new diagnostic markers of unilateral CT paralysis. The results are discussed with respect to their clinical implications, and the necessity to explore both females and clinical populations to better appreciate the clinical utility of these diagnostic signs.

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ACKNOWLEDGMENTS

I would like to express my genuine gratitude to Dr. Nelson Roy, for his encouragement and patience throughout the course of this great project. He has provided excellent advice which has benefited me greatly in many facets of my graduate school life, and he has represented a standard of effort, thought, and excellence that I hope will remain with me throughout my life.

I would also like to thank those with whom I had the privilege to work while completing this project: Dr. Marshall Smith, for his taking every opportunity to educate; Dr. Christopher Dromey, for his invaluable skills and contributions to our data collection; Dr. Ray Merrill, who greatly contributed to our various statistical analyses; Cara Sauder, Clinical Director of the University of Utah Voice Disorders Center, for supporting the research projects by allowing access to voice center space and equipment, and for participating in data acquisition; and Dr. Kristine Tanner, for her role in data acquisition.

The expert raters who generously volunteered of their time to complete many hours or rating stroboscopic samples should also be thanked and acknowledged: Steven Bielamowicz, M.D.; Mark Courey, M.D.; Gaelyn Garrett, M.D.; Albert Merati, M.D.; Gregory Postma, M.D.; Robert Sataloff, M.D.; James Thomas, M.D.; Alison Behrman, Ph.D.; Douglas Hicks, Ph.D.; Robert Hillman, Ph.D.; Bruce Poburka, Ph.D.; Joseph Stemple, Ph.D.; and Ed Stone, Ph.D.

A special thank-you to my children who were so patient and loving, even when they didn't get to see their Daddy as much as they would like. Lastly, I would like to thank my wonderful wife, whose superior strength and support has sustained me through the conclusion of graduate school and this thesis, neither of which I could have completed without her.

INTRODUCTION

The external superior laryngeal nerve (ESLN) is one of two branches of the Xth cranial nerve (vagus) responsible for motor innervation of the larynx (see Figure 1). The ESLN supplies the cricothyroid (CT) muscle, which is a vocal fold tensor contributing to pitch elevation (Hong et al., 1998). The CT is a fan-shaped muscle with two distinct bellies of fibers: the lower pars oblique and the upper or anterior pars recta (see Figure 2). As the anterior fibers contract, the distance between the thyroid cartilage and the cricoid arch decreases, consequently increasing distance between the thyroid cartilage and the vocal processes. Thus, the vocal folds are elongated and are placed under increased tension, resulting in pitch elevation (Zemlin, 1998). The recurrent laryngeal nerve (RLN), another branch of the vagus, innervates the intrinsic laryngeal muscles responsible for vocal fold adduction and abduction. While partial or complete RLN denervation results in vocal fold paresis or paralysis, respectively, the phenomenological features of ESLN denervation remain elusive and a source of considerable debate. Over 25 years ago, Abelson and Tucker (1981) first underscored this controversy when they stated "the diagnosis of superior laryngeal nerve paralysis is infrequently made because of disagreement concerning laryngeal findings in unilateral cricothyroid muscle dysfunction" (p. 463). Regrettably, over the past 25 years, few advances have been made in our understanding of the voice and laryngeal manifestations of unilateral CT dysfunction and hence, diagnostic accuracy. Currently, no consensus exists regarding the

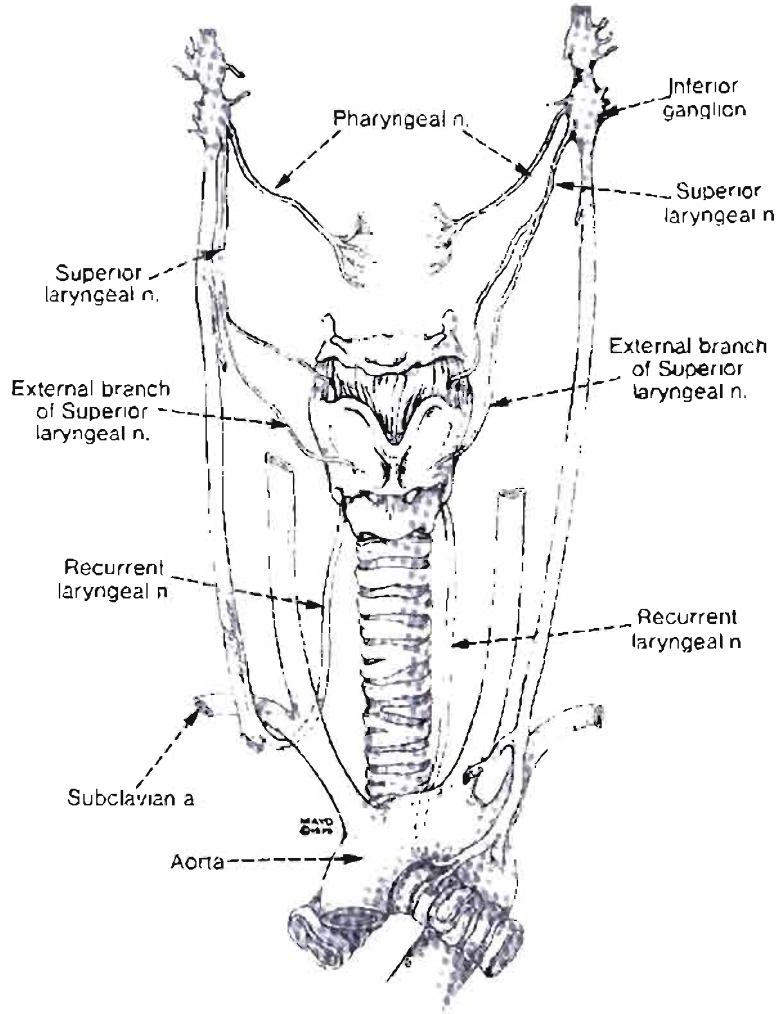


Figure 1. Innervation of the RLN and SLN branches of the vagus nerve.
Note. From *Clinical Voice Disorders, Third Edition* (p. 74), by A. E. Aronson, 1990, New York: Thieme Medical Publishers, Inc. Copyright 1990 by Thieme Medical Publishers, Inc. Reprinted with permission.

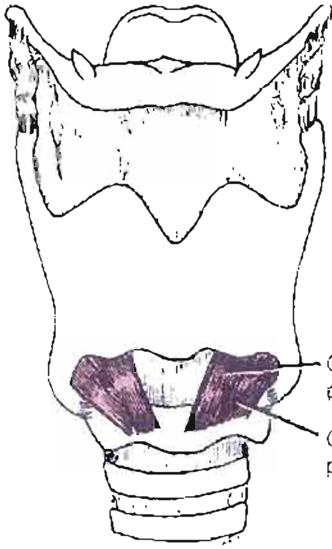


Figure 2. The two bellies of the cricothyroid muscle (pars recta & pars oblique).
Note. From *Speech and Hearing Science: Anatomy and Physiology, Fourth Edition* (p. 135), by W. R. Zemlin, 1998, Needham Heights, Massachusetts: Allyn & Bacon. Copyright 1998 by Allyn & Bacon. Reprinted with permission.

clinical features considered pathognomonic of external SLN denervation. To address this longstanding controversy, this investigation proposes to model acute, unilateral, ESLN denervation by chemically blocking the ESLN with lidocaine HCL. The purpose of this investigation is twofold: (1) to identify the salient laryngeal features associated with acute denervation (i.e., the pathognomonic features of unilateral CT dysfunction), and (2) to identify a set of laryngeal tasks that maximally provoke or reveal SLN dysfunction, thereby contributing to a set of diagnostic tasks/markers that will improve diagnostic confidence and accuracy during clinical assessment.

Laryngeal Manifestations of SLN Denervation

At the time of Abelson and Tucker's (1981) study, various opinions had already been established regarding the precise laryngeal manifestations of ESLN paralysis. A recurrent feature in most descriptions involved rotation of the larynx, presumably due to asymmetric CT dysfunction. One classic view held that ESLN denervation caused the weakened ipsilateral cord to be shortened and at a lower level, while the anterior larynx shifted to the intact CT side creating an oblique glottis, with the posterior larynx rotated toward the weakened side (Faaborg-Anderson & Jensen, 1964; Ward, Berci, & Cacaterra, 1977). However, as Abelson and Tucker reported, there was considerable disagreement and controversy surrounding this view. For instance, while some authorities confirmed that the anterior commissure rotated to the paralyzed side (New & Childrey, 1930), other experts asserted that the posterior larynx rotated as well, but there was no consensus as to which side (Arnold, 1961). Still others failed to consistently find an oblique glottis (Dedo, 1970). In an attempt to resolve the controversy, Abelson and Tucker used local anesthetic to temporarily paralyze the SLN in a small number of volunteers ($n = 4$). Laryngoscopy during the block showed a symmetrical larynx at rest, but during phonation, the posterior commissure pulled toward the side of temporary paralysis. Also, the ipsilateral vocal fold was slightly bowed and appeared shorter as compared to the contralateral fold. Abelson and Tucker concluded that ESLN paralysis in humans can be suspected when "an oblique glottic chink is observed during phonation. . . . This is caused by rotation of the posterior commissure towards the side of the paralysis. The aryepiglottic fold on the side of the paralysis is shortened, and the aryepiglottic fold on the opposite side is lengthened" (p. 469). Later, Tanaka, Hirano, and Umeno (1994) confirmed that 9 of 12 patients with ESLN paralysis clearly showed rotation of the posterior glottis to the paralytic side during pitch elevation primarily.

Although Abelson and Tucker's (1993) experiment, combined with Tanaka and colleague's (1994) clinical report, seemed to briefly quiet the controversy, results from more recent research have seriously questioned the worth of larynx rotation as a salient laryngoscopic sign of ESLN paralysis. Several researchers have identified a number of additional laryngostroboscopic characteristics that occurred more frequently. For instance, in a population of 126 patients that included ESLN paresis and paralysis, Durson et al. (1996) reported abnormalities in vocal fold lag, asymmetry, and height disparity (scissoring), as the most distinct findings of ESLN dysfunction, as well as decreased amplitude and mucosal wave of the affected fold. Interestingly however, Durson and colleagues did not identify larynx rotation as a salient feature of ESLN paralysis. The most common symptoms reported by patients were vocal fatigue, hoarseness, volume disturbance, and loss of range.

Contrary to larynx rotation, a number of recent studies have identified *sluggishness* of the ipsilateral vocal fold during repetitive ad/abduction tasks, and decreased longitudinal tension as the sine qua non of ESLN injury. For instance, Eckley, Sataloff, Hawkshaw, Spiegel, and Mandel (1998) reported on a group of 56 adults with diagnosed ESLN paresis or paralysis (based upon laryngeal electromyographic (LEMG) findings). The authors described 3 severity levels of paresis with associated laryngeal findings: mild SLN denervation showed a slight sluggishness of the weakened side, and usually a mild deficit in the ability to increase longitudinal tension during pitch elevation; in moderate SLN denervation, the sluggishness and deficit in pitch elevation were obvious; severe SLN denervation manifests with almost no motion of the CT on the affected side, but tone was still present. Common symptoms among the patients in this study included vocal fatigue, breathiness, volume disturbance, hoarseness, and loss of high pitch range. Again, there was no reporting of rotation of the larynx as a distinct feature of ESLN paresis or paralysis.

Heman-Ackah and Batory (2003) also emphasized sluggishness of the affected vocal fold as evidence of SLN injury. The authors declared that if the integrity of the cricothyroid and thyroarytenoid joints are shown to be normal, hypomobility in the distribution of the ESLN is manifested by *sluggishness in adduction* and *longitudinal tension,* observed especially during rapid repetition of /i/ and /hi/. Furthermore, Rubin et al. (2005) asserted that vocal fold lag (sluggishness), especially during fatiguing repetitive phonatory tasks (RPT), was a hallmark of ESLN injury, explaining that paretic nerves fatigue more quickly than normal nerves. Rubin and colleagues warned that ESLN paresis can be misinterpreted as RLN paresis because "vocal fold lag . . . can present as sluggish abduction as well as adduction" (p. 685). They argued that RPTs were useful diagnostic tasks for predicting ESLN paresis.

However, in an apparent contradiction of their previous findings, Heman-Ackah and Barr (2006) stated that in cases where mild hypomobility is observed on physical examination, "*no muscle pattern* of hypomobility can identify the paretic nerve or nerves accurately" (p. 277). The conclusion reflects the authors' attempts to reconcile poor agreement between the hypomobility observed during laryngoscopy and the actual LEMG evidence that identified which side and which nerves were apparently affected. Heman-Ackah and Barr reasoned that "paresis of the laryngeal nerves results in asymmetrical muscle forces in the larynx, and depending upon the relative compensation from the unaffected muscles and the degree of pull from the affected muscle, the pattern of hypomobility observed may not necessarily coincide with the expected mobility pattern" (p. 278). Therefore, this finding casts considerable doubt regarding the diagnostic precision of vocal fold lag as a reliable marker of SLN injury.

A recent study by Mendelson, Sung, Berke, and Chetri (2007) examined the vibratory pattern of the mucosal edges of the vocal folds of a person with SLN paralysis using videostrobokymography. Laryngeal kymography provided coronal views of the vocal fold vibration over a period of time. Results showed "an undulating motion of the horizontally shifting glottic space as the medial edges of the vocal folds chased each other 90° out of phase" (p. 85). The authors believe this undulating motion or phase asymmetry is pathognomonic of ESLN paralysis, but concede that it may not be present in every case because a periodic vibration is necessary to appreciate this motion stroboscopically. This periodic vibration has not been found to be consistent in cases of ESLN paralysis.

From the previous literature review, it is clear that considerable controversy remains regarding which voice and laryngoscopic features, if any, should be considered pathognomonic of pure ESLN denervation. In the context of this uncertainty, and in the absence of any recent studies designed to assess the pure effects of acute ESLN denervation, it is impossible to know the true prevalence of ESLN denervation, and whether this clinical entity is in fact under-recognized and/or underdiagnosed.

To complicate matters, recent studies which have examined clinical populations with LEMG are inherently problematic. In these studies, the investigators have usually identified some type of atypical laryngeal movement pattern, and then sought LEMG evidence to confirm or refute their clinical impressions. This has led to the conclusion that LEMG is necessary to correctly identify ESLN paresis or paralysis (Heman-Ackah & Barr, 2006; Rubin et al., 2005; Koufman, Postma, Cummins, & Blalock, 2000). However, in this regard, LEMG by itself is not without its detractors. Woodson (1998) stated that LEMG must be interpreted, and therefore cannot be treated like a "standardized test that results in a quantitative measurement" (p. 476). Furthermore, a recent evidence-based systematic review conducted by the American Association of Electrodiagnostic Medicine of the medical literature pertaining to the clinical application of LEMG (1944 to 2001), concluded that although anecdotal reports existed to support the clinical utility of LEMG, there were no evidence-based data to support the value of LEMG for uses other than Botox injection in spasmodic dysphonia. While LEMG is currently being used with greater frequency for the diagnosis, prognosis, and treatment of voice disorders, unfortunately, relatively few professionals trained in LEMG have practical experience in LEMG or a comprehensive understanding of the anatomy and physiology of laryngeal disorders. The task-force concluded that additional evidence-based studies are recommended to determine the following: the value of LEMG for each of the clinical uses; optimal electrode type for specific clinical purposes; the validity and reliability of techniques used for quantification of LEMG signals; the predictive and diagnostic accuracy of LEMG findings and their relation to treatment outcomes.

Purpose of the Study

It is important to identify what laryngeal characteristics, if any, are unique to unilateral ESLN denervation in order to facilitate future diagnosis. Therefore, this investigation proposes to model "in-vivo" acute, unilateral ESLN denervation in 10 vocally normal, healthy males by temporarily blocking the ESLN using lidocaine HCL with epinephrine, and verifying selective denervation using LEMG. Laryngeal function before and during SLN block will be evaluated using flexible laryngostroboscopy. By surveying a broad range of vocal tasks and maneuvers before and during the ESLN block, two specific hypotheses will be addressed: (1) is there hypomobility of one or both of the vocal folds, and (2) is there canting (i.e., axial rotation) of the larynx during high pitch production as a result of ESLN paralysis? It is also the aim of this study to identify a set of laryngeal tasks that maximally provoke or expose ESLN dysfunction when present, thereby contributing to the development of improved diagnostic protocols to be used during clinical examination.

METHODS

Participants

This study evaluated 10 healthy males, ages 19 through 29 years, with a mean of 25 years. Prior to testing, a self-assessment voice questionnaire (VRQOL) was administered to each subject. Subject scores ranged from 97.5 to 100 (normal range = 90-100), with an average score of 99.8. All subjects were nonsmokers, with no history of (1) laryngeal dysfunction or disease as determined by laryngeal examination and self-report; (2) pulmonary dysfunction or any other disease process that has a known influence on respiration or phonation as indicated by self-report; (3) CVA or other neurological abnormalities; (4) liver disease or dysfunction; (5) known coronary artery disease; (6) or singing voice training. Individuals under the age of 18 were not included because the experimental procedures used were inappropriate for children. Participants were recruited through advertisements. Informed consent, conducted by the investigators, was obtained prior to testing. Participants were compensated $150.00 for their time.

Procedures

All procedures and data acquisition were conducted in the University of Utah Voice Disorders Center, a clinical entity within the Surgery Specialty Center located in the CAMT building in Research Park, which is part of the University of Utah Health

Sciences Network. A licensed physician was present for the entire procedure. The following measures were acquired at two times and in the following order: Time 1 = Baseline recording; and Time 2 = during the lidocaine ESLN block (with LEMG confirmation of complete CT denervation).

Initially, normal vocal fold structure and function was established using flexible videolaryngostroboscopy. A flexible endoscope was placed transnasally and positioned in the mid-pharyngeal region to optimally view the endolarynx. Stroboscopic characteristics of glottic closure pattern, amplitude of vocal fold excursion, mucosal wave, phase closure, and symmetry were recorded/assessed during production of various vocal tasks. The following vocal tasks were produced with a soft, comfortable, and loud voice: sustain /i/ at a modal pitch; sustain /i/ at a low pitch; sustain /i/ at a high pitch; glissando up producing /i/ (rapid slide from a comfortable pitch to the highest possible pitch); glissando down producing /i/ (rapid slide from a comfortable pitch to the lowest possible pitch). The subjects were asked to repeat different syllables (/i/, /hi/, & /pi/) as quickly and steadily as they could for at least 7 seconds. These are known as laryngeal diadochokinetic rates (DDKs). These laryngeal DDKs were produced at low, modal, and high pitch levels. Also produced at these pitch levels was a task that required the subject to briefly produce /i/ following a rapid sniff of air through the nose (i.e., sniff /i/, sniff /i/, sniff /i/). Finally, to confirm intact laryngeal sensation and ensure that no anesthetic diffused to the internal branch of the SLN, the participant's laryngeal adductor response was evaluated by gently contacting the left and right aryepiglottic folds with the scope tip. In all cases, the reflexive adduction of the aryepiglottic folds and vocal folds verified that the internal branch of the SLN, which provides sensation above the vocal folds, was unaffected by the external SLN block. For a review of all procedures and instructions see Appendix A.

Procedure for Infiltration of Lidocaine HCL with Epinephrine

A licensed, board certified laryngologist, Dr. Marshall Smith, palpated the neck to identify the space between the carotid artery and the trachea on the right side. With the head extended up and to the right to stretch the neck in the desired region, 2% lidocaine HCL with epinephrine diluted at 1:100,000 was injected into the vicinity of the external branch of the SLN as it courses on its way to the larynx. This location is over the mid-thyroid ala, just anterior to the posterior margin of the cartilage, where the sternothyroid muscle inserts on the cartilage. This location is well away from the major vessels of the neck. The injection began with an initial volume of 0.5 cc, and subsequent injections were administered in 0.5 cc increments until LEMG evidence of complete abolition of ipsilateral CT muscle activity was obtained (see Table 1 for a complete description of exact quantities for each subject). A waiting period of 3 to 4 minutes was observed between injections to permit time for lidocaine to diffuse before administering a subsequent injection. Successful infiltration into the ESLN region provided a peripheral nerve block for approximately 60-90 minutes. Lidocaine HCL blocks the nerve as a result of stabilizing "the neuronal membrane by inhibiting the ionic fluxes required for the initiation and conduction of impulses thereby effecting local anesthetic action" (PDR, 2002).

LEMG Recordings

During the block, the LEMG signal was monitored during maximal effort tasks (i.e., sustained pitch elevation/falsetto and/or valsalva, glottic clicks/loud phonation) to observe the recruitment patterns in the ipsilateral CT and TA muscles. LEMG provides information regarding recruitment (number of activated motor units) within laryngeal muscles, and it was used to confirm that complete, selective denervation of the CT had been achieved and function of the thyroarytenoid (TA) muscle, an intrinsic laryngeal muscle innervated by the RLN, was preserved. LEMG in this context was used to confirm that no diffusion of lidocaine to unintended nerves (i.e., the RLN) had occurred.

Laryngeal EMG recordings in both the CT and TA muscles verified that the ipsilateral CT had been denervated during the lidocaine block (see Figure 3). All EMG recordings were completed using bipolar hooked-wire electrodes constructed from pairs of insulated 0.0002 inch diameter stainless steel bifilar wire, inserted through a 1.5 inch 25 gauge needle. The electrodes were inserted percutaneously into the ipsilateral TA and CT muscles. After electrode insertion and verification maneuvers, subjects were recorded with three trials of phonation of /a/ at normal pitch, and during glottal clicks, valsalva (i.e., effortful breath hold) maneuvers, and head flexion against resistance. The first three conditions were to evaluate TA function, whereas the head flexion against resistance task was designed to confirm that the LEMG electrode was not in an anterior neck muscle such as the sternothyroid muscle, which overlies the CT. To maximally provoke CT activation, recordings were made during a sustained falsetto production. This maximal effort task was used repeatedly to assess recruitment patterns in the CT muscle. Verification of complete and selective ESLN block was obtained when recruitment was

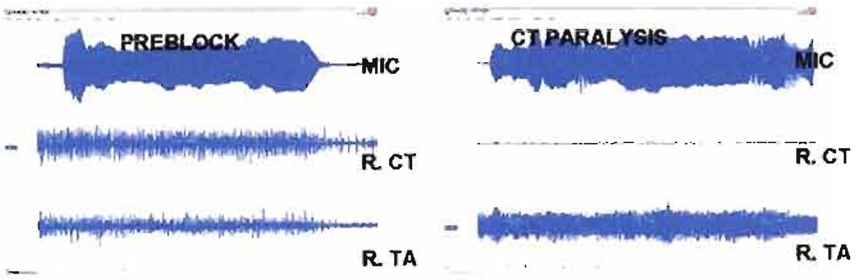


Figure 3. LEMG recordings for the R. CT and TA muscles acquired during the same maximum effort task at two points during the experiment (i.e., preblock, during block/CT paralysis).

abolished in the ipsilateral CT, but maintained at normal levels in the TA. At this time, all measures were repeated. As the effect of the lidocaine abated and full vocal fold mobility returned, complete return of normal voice was observed. All subjects tolerated the procedure without any adverse effects. VRQOL data collected approximately 6 months postexperiment via telephone interviews confirmed return of normal voice in all participants and VRQOL scores which were compatible with their baseline vocal function. Subject scores ranged from 90 to 100 (normal range = 90-100), with an average score of 98.5 (Table 1). Additionally, each subject was asked to compare his current voice to his voice prior to the study. The subjects were given the rating options of no problem, mild problem, moderate problem, and severe problem. All subjects reported their current voices as having "no problem," thus verifying no residual or untoward voice effects of any aspect of the experiment.

Ratings

Ten vocal tasks were selected to be reviewed by raters: (normal pitch normal loudness (NPNV), normal pitch loud volume (NPLV), high pitch normal loudness

Table 1. VRQOL ratings preblock and at a 6 month follow-up, and lidocaine amount required to obtain block of CT.

Subject #	Code	Age	VRQOL Score Pre-block	VRQOL Score 6 month post	Lidocaine (cc)
1	M01	28	100	100	2.8
2	M02	25	100	100	3
3	M03	25	100	95	2
4	M04	19	100	100	0.5
5	M05	25	100	100	2
6	M06	20	97.5	90	1
7	M09	27	100	100	2
8	M10	24	100	100	1
9	M11	28	100	100	2
10	M12	29	100	100	1

(HPNV), high pitch loud volume (HPLV), glissando up normal volume (GUNV), glissando up loud volume (GULV), DDK /hi/ (DDK hee), normal pitch sniff /i/ (NP Sniff), high pitch sniff /i/ (HP Sniff), and whistling *Happy Birthday* (WHISTLE). These vocal tasks were selected on the basis of the review of the literature, which indicated that these particular tasks had the potential to reveal ESLN-related dysfunction. Thus, tasks that sampled normal and high pitch were selected, as well as tasks related to vocal fold mobility.

For the purpose of establishing standardized, blinded, visual-perceptual ratings of FVLS recordings, the complete, original baseline and during-block recordings for each subject were reviewed, and a log was created outlining every production of each task to determine its candidacy for inclusion in the final rating tasks. As needed, comments were added regarding the quality of a production (i.e., poor angle, talking over the subject by the examiner, etc.) to facilitate future selection of productions to be rated for each task. One clip of each token produced by the subjects was then selected and stored as a .wmv file using Pinnacle Studio Plus (Version 11), a video editing software program. To permit objective comparisons of pre- and during-block video samples, and avoid any potential bias, video clips were selected upon the following criteria: for voice tasks with two or more productions (i.e., tokens), the second production/token was selected to ensure consistency; if the second production was extremely poor in quality (i.e., duration too short, view obscured, movement artifact, etc.), the next production was selected, and so on; if all productions were poor in quality, the best visual representation was selected; for tokens with only one production, a clip was made regardless of its quality. Once a token was selected, it was copied from the original recording and saved as an individual clip in Pinnacle Studio Plus. A table was created for all subjects, listing which productions were selected for each token.

For the purpose of creating the ten movies, which would be viewed by expert raters, a movie script was created for each task. The movie script outlined the specific order in which the subjects' clips were to be presented to the raters for each task. Ten movies, which corresponded to 10 vocal tasks, were created. For each movie, individual subjects' pre- and during-block productions were presented as a pair; however, the order (i.e., pre- vs. during-block production) was randomized, as was the order of the subjects. To permit estimates of intrarater reliability, pre- and during-block samples from two subjects (i.e., approximately 20% of samples) were randomly selected and repeated at the end of the movie. For each new movie/task, two new subjects were randomly selected for this reliability measure. Raters were blinded as to the order of the subjects, as well as the two additional ratings. Once the scripts were completed for each token, Pinnacle Studio was used to create movie data files for each token. Each movie data file included title screens indicating which task was being rated, which set (subject), and which sample (pre/during). For example: "Normal Pitch Normal Loudness Set 1. Sample A." The files were created according to the order of the scripts, and burned onto compact discs.

Each rater received three compact discs: disc 1 contained the files for Normal Pitch Normal Volume, Normal Pitch Loud Volume, High Pitch Normal Volume, and Glissando Up Normal Volume; disc 2 contained the files for Normal Pitch DDK /hi/, Normal Pitch Sniff /i/, High Pitch Sniff /i/, and Whistle; disc 3 contained the files for High Pitch Loud Volume and Glissando Up Loud Volume. Each of the three discs was sent to 11 raters (5 Speech-Language Pathologists and 6 Board-Certified Otolaryngologists). Along with these discs, the raters were given a detailed set of instructions (Appendix B) and rating forms (Appendix C). The ratings and their operational definitions were selected to provide a comprehensive assessment of laryngeal appearance and function, and on the basis of a review of the literature. Certain parameters were also included because they had been previously identified as laryngeal manifestations of ESLN dysfunction.

RESULTS

This was a pre-post repeated measures design of 10 participants. Thirteen male participants were recruited and originally participated. However, data from 3 subjects could not be used because one subject experienced a vasovagal reaction upon insertion of the flexible nasoendoscope into anterior nares, and the experiment was discontinued. In a second participant, lidocaine block of the ESLN was not achieved despite repeated attempts, and in a third subject, both the Right RLN and ESLN were blocked concurrently based upon LEMG evidence (i.e., obliteration of both CT and TA muscle activity) and visual inspection of the larynx which confirmed right vocal fold immobility confirming right RLN denervation. Thus, the data reported here reflect the remaining 10 subjects who completed all aspects of the experimental protocol.

Reliability of FVLS Ratings

Prior to embarking on an analysis of the results, estimates of inter- and intrarater reliability of FVLS tasks and parameters were calculated. Each of the parameters within the ten FVLS tasks required ordinal responses with the exception of "overall rating of the larynx," which was measured in millimeters using a visual analog scale ranging from 1 (normal) to 100 (profoundly abnormal). Given the parametric nature of these data, inter-rater reliability for "overall rating of the larynx" was assessed using the intraclass correlation coefficient (ICC), whereas interrater reliability of ordinal parameters within each task was assessed using Gwet's robust measure of multirater agreement (similar to Fleiss' generalized kappa), a nonparametric data analysis approach (Fleiss, 1971; Gwet, 2001). Gwet's measure (called AC1) is resilient to commonly cited limitations of the kappa, namely sensitivity to raters' classification probabilities and trait prevalence in the participant population (Gwet, 2002). These measures are interpreted similar to Kappa, with Byrt (1996) proposing the following guidelines: excellent agreement (0.93-1.00), very good agreement (0.81-0.92), good agreement (0.61-0.80), fair agreement (0.41-0.60), slight agreement (0.21-0.40), and poor agreement (0.01-0.20).

Table 2 shows the task-level ICCs for "overall rating of the larynx." These task-related ICCs ranged from 0.756 to 0.914, which indicated "good" agreement for NPNV and HPLV and "very good" agreement for the other tasks.

Interrater reliability of ordinal data using the AC1 measure are presented in Table 3 for each parameter and across tasks. Using Byrt's categorization of agreement, inspection of Table 3 confirms that interrater agreement was generally good or very good for the majority of the parameters, with exception of the parameter "supraglottic activity"

Table 2. Interrater reliability of the overall rating of the larynx.

Task	ICC	Agreement
NPNV	0.781	Good
NPLV	0.914	Very Good
HPNV	0.855	Very Good
GUNV	0.827	Very Good
HPLV	0.756	Good
GULV	0.829	Very Good
HEE	0.841	Very Good
NP Sniff	0.880	Very Good
HP Sniff	0.843	Very Good
Whistle	0.816	Very Good

Table 3. Interrater reliability for each FVLS parameter across voice tasks.

	Normal Pitch Tasks			High Pitch Tasks				
	NPNV	NPLV	Agreement	HPNV	GUNV	HPLV	GULV	Average Agreement
Glottic Closure Pattern	.68	.71	G	.47	.39	.65	.47	F
Vertical Level of Vocal Fold Approx	.85	.92	VG	.84	.89*	.82*	.88*	VG
Size of Glottic Gap	.63	.74	G	.57	.54	.58	.50	F
Bowed Vocal Fold	.87	.82	VG	.81	.85	.89	.87	VG
Length of Vocal Folds				.81	.89†	.82	.89	VG
Vibratory Behavior: Right	.85	.85	VG	.53	.64	.82	.68	G
Left	.88	.79	VG	.55	.65	.77	.66	G
Phase Symmetry	.78	.80	G	.65	.73	.68	.64	G
Supraglottic Activity	.38	.30	S	.31	.31	.27	.28	S
Aryepiglottic Fold Length	.77	.76	G	.67	.57	.79	.78	G
Axial Rotation of the Larynx	.65	.68	G	.69	.52	.63	.64	G
Petiole of the Epiglottis	.65	.70	G	.65	.62	.73	.68	G

*w/o R1 (missing data)

† w/o R3 and R9 (missing data)

E= Excellent, VG= Very Good, G= Good, F= Fair, S=Slight, P= poor

Table 3 continued

	Mobility Task		Sniff Tasks				
	DDK HEE	Agreement	NP Sniff	HP Sniff	Agreement	Whistle	Agreement
Vocal Fold Mobility: Right VF	.70	G	.76	.69	G	.58	F
Left VF	.79	G	.80	.83	G/VG	.77	G
Sluggishness /Vocal Fold Lag: Right VF	.63	G	.71	.64	G	.51	F
Left VF	.69	G	.75	.78	G	.73	G
Symmetry of Vocal Fold Movements	.60	G	.65	.65	G	.57	F
Vocal Fold Edge Shape: Right VF	.84	VG	.86	.79	G/VG	.79	G
Left VF	.93	E	.80	.76	G/VG	.88	VG
Supraglottic Activity	.52	F	.33	.35	S	N/A	N/A
Axial Rotation of the Larynx	N/A	N/A	.58	.63	F/G	N/A	N/A

N/A= This parameter not assessed during this particular task
E= Excellent, VG= Very Good, VG= Good, F= Fair, S=Slight, P= poor

which ranged from "fair" to "slight." Because of the poor reliability across raters for supraglottic activity, this parameter was dropped from any subsequent interpretation of the results.

To assess intrarater reliability for each task and parameter, two randomly selected participants (i.e., approximately 20% of ratings) were rated twice at the end of each rating task. For the "overall rating of the larynx" scale, measures of simple association between the originally scored and repeated scored values across the raters are shown in Table 4. Significant positive agreement was observed between original and repeated ratings. For the items rated on an ordinal scale, intrajudge reliability was assessed using Spearman Correlation Coefficient according to Task and rater (Table 5). Raters 3, 4, and 9 had the lowest correlations but, with few exceptions, the correlation coefficients were significantly positive. Therefore, based upon respectable estimates of inter- and intra-rater reliability and agreement for both parametric and nonparametric FVLS data, no raters were dropped from the analysis, and the reporting of the results that follow includes all data from all raters.

Table 4. Intrarater reliability for the parameter "overall rating of the larynx".

Task	**Spearman's Rho**	**P value**
NPNV	0.66	< 0.0001
NPLV	0.56	< 0.0001
HPNV	0.67	< 0.0001
GUNV	0.72	< 0.0001
GULV	0.84	< 0.0001
HPLV	0.68	< 0.0001
HEE	0.68	< 0.0001
NP Sniff	0.68	< 0.0001
HP Sniff	0.86	< 0.0001
Whistle	0.67	< 0.0001

Table 5. Intrarater reliability across tasks.

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11
NPNV	.73	.46	.44	.72	NS	.54	.71	.70	.56	.46	NS
NPLV	.90	.82	.33	.56	.87	.81	1.00	.73	.51	.89	.48
HPNV	.74	.89	.45	.29	.83	.77	.86	.60	NS	.77	.80
GUNV	.85	.84	.51	.60	.77	.90	.83	.62	.54	.70	.90
GULV	.74	.85	.87	.51	.96	.84	.69	.89	.37	.81	.81
HPLV	.56	.99	.52	.65	.76	.87	.74	.91	.39	.62	.94
HEE	.65	.61	.76	.49	.48	.54	.52	.85	?	.45	?
NP Sniff	.54	.40	.56	NS	.79	.71	NS	.89	.79	.85	NS
HP Sniff	.56	.62	.55	.49	?	.66	.48	.84	NS	.68	.44
Whistle	?	NS	.68	NS	1.00	?	.69	NS	.41	?	.46

NS: Not significant at 0.05 level.
? : No variability in original scores and/or repeat scores.

FVLS Results: Parametric Data

To assess the change in overall laryngeal function related to the nerve block, the pre- and during-block mean scores from the visual analog scale entitled "overall rating of the larynx" for each task were compared using paired-samples t-tests. Table 6 confirms that a noticeable deterioration in overall laryngeal function was observed during the block condition, as mean ratings significantly worsened from before to during nerve block for the high pitch tasks (except HPNV) and HP Sniff. However, there was no significant deterioration in laryngeal function for any of the normal pitch tasks or the mobility tasks, including ddK Hee task, NP sniff, and Whistle.

Table 6. Mean overall rating of the larynx before and during nerve block

	Before	During	Difference	T statistic	P value
NPNV	19.6	24.5	4.9	1.43	0.1876
NPLV	21.2	25.6	4.4	0.74	0.4820
HPNV	25.3	32.1	6.8	1.53	0.1603
GUNV	21.4	32.8	11.4	4.16	0.0032
HPLV	21.5	29.5	8	2.88	0.0207
GULV	22.5	31.7	9.2	2.29	0.0516
HEE	20.3	18.8	-1.5	0.30	0.7692
NP Sniff	18.1	19.3	1.2	0.28	0.7904
HP Sniff	14.4	25.5	11.1	2.53	0.0391
Whistle	19.1	21.3	2.2	0.89	0.4003

FVLS Results: Nonparametric Data

As a first approach to analysis of the ordinal (i.e., categorical) data and to determine omnibus changes in laryngeal function associated with unilateral CT dysfunction secondary to ESLN block, ordinal ratings for each parameter were first dichotomized into "normal" or "non-normal." Normal ratings were all ratings receiving a score of "1" on each parameter, whereas any ratings greater than or equal to 2 were assigned "2" and were considered "non-normal." Thus, using this approach, all judges' ratings for each task and parameter, before and during nerve block, were first categorized as "normal" vs. "non-normal" and subsequently evaluated using the chi-square test of equal proportions. By dichotomizing the data in this way, the chi-square test served essentially as a protected omnibus test comparing the overall proportion of normal vs. non-normal ratings across all parameters for a specific vocal task, thereby directing our attention to parameters which changed significantly during the block. These parameters would subsequently undergo closer post-hoc examination and inspection to determine possible patterns of CT dysfunction. The percentage of normal ratings before and during nerve block is presented by task and other parameters in Table 7. Note: highlighted percentages are significantly different between before and during nerve block periods ($p<.05$). Inspection of Table 7 reveals that the high pitch voice production tasks including HPNV, GUNV, HPLV, GULV, and HP Sniff all seemed to reveal aspects of ESLN-block induced dysfunction at this gross level of analysis, with numerous parameters rated "non-normal" during the block. In the previous analysis of the visual analog scale results, these vocal tasks were also identified as revealing overall laryngeal dysfunction. The parameters of axial rotation and epiglottic petiole deviation were uniformly rated as less

Table 7. Percentage with normal rating before and during nerve block according to task and item

	Normal Pitch Tasks				High Pitch Tasks							
	NPNV		NPLV		HPNV		GUNV		HPLV		GULV	
Item	B	D	B	D	B	D	B	D	B	D	B	D
Glottic Closure Pattern	58%	64%	79%	68%	25%	50%	34%	60%	25%	56%	34%	55%
Vertical Level of Vocal Fold	94%	91%	98%	94%	94%	87%	96%	92%	89%	91%	94%	92%
Size of Glottic Gap	66%	66%	79%	68%	27%	51%	39%	63%	34%	59%	43%	57%
Bowed Vocal Fold	97%	89%	90%	88%	90%	86%	97%	84%	97%	91%	97%	89%
Length of Vocal Folds	---	---	---	---	90%	86%	96%	92%	96%	81%	98%	89%
Vibratory Behavior: Right	92%	90%	94%	91%	71%	69%	82%	74%	92%	88%	83%	81%
Left	96%	92%	86%	88%	69%	70%	78%	79%	89%	85%	81%	81%
Phase Symmetry	85%	72%	77%	72%	70%	62%	80%	76%	80%	67%	68%	60%
Supraglottic Activity	43%	47%	25%	25%	36%	32%	29%	16%	25%	18%	19%	18%
Aryepiglottic Fold Length	82%	84%	88%	76%	81%	71%	82%	64%	94%	81%	83%	78%
Axial Rotation of the Larynx	83%	65%	80%	47%	75%	47%	80%	43%	82%	57%	76%	60%
Petiole of the Epiglottis	82%	69%	79%	77%	83%	65%	86%	53%	85%	65%	83%	73%

B=Before block D=During block

Table 7 continued.

	Mobility Task		Sniff Tasks					
	HEE		NP Sniff		HP Sniff		Whistle	
Item	B	D	B	D	B	D	B	D
Vocal Fold Mobility: Right VF	81%	81%	88%	84%	86%	74%	67%	64%
Left VF	86%	90%	88%	85%	94%	77%	82%	80%
Sluggishness /Vocal Fold Lag: Right VF	74%	76%	82%	83%	87%	69%	74%	70%
Left VF	79%	83%	86%	82%	95%	73%	85%	84%
Symmetry of Vocal Fold Movements	57%	61%	78%	64%	79%	44%	72%	69%
Vocal Fold Edge Shape: Right VF	90%	90%	91%	94%	88%	87%	92%	82%
Left VF	93%	98%	95%	78%	91%	79%	97%	88%
Supraglottic Activity	55%	65%	47%	55%	56%	48%	---	---
Axial Rotation of the Larynx	---	---	72%	70%	88%	55%	---	---

B=Before block D=During block

Note: highlighted percentages are significantly different between before and during nerve block periods (p<.05).

normal during the block condition for most of these tasks. In contrast however, the mobility tasks such as ddK Hee, NP Sniff, and whistle all seemed to be less sensitive to unilateral CT dysfunction. It is also interesting to note that there was a significant increase toward "normal" ratings in glottis closure pattern and size of glottis gap for HPNV, GUNV, HPLV, and GULV, perhaps suggesting a qualitative change in glottic closure patterns.

To improve the precision and interpretation of the omnibus chi-square results presented in Table 7, a closer examination of the change in ratings for each individual subject was undertaken. In this regard, the modal rating (defined as the most frequent rating among the 11 raters) was first determined for each subject, for each task and parameter, and this was considered the "true" pre- and during-block rating for that particular subject. Given the small number of subjects and multiple categories/levels for each parameter (e.g., 1 = normal, 2 = mild, 3= moderate, 4= severe), we again dichotomized ratings into "normal" vs. "non-normal," as previously. Therefore for each subject, and for each task and parameter, the modal rating (either 1= normal, or 2 = non-normal or any non-"one" rating) was determined for the pre- vs. during-block condition. An analysis in the change in modes was then computed using the McNemar test for correlated proportions. The McNemar test determines if the proportion of subjects judged "normal" at time 1 (i.e., preblock) is the same as the proportion of subjects judged normal at time 2 (i.e., during block). Based upon a significant McNemar test ($p<.2$), additional inspection of individual subject data was undertaken to precisely identify the type or pattern of change observed (Note: we used the liberal $p<.2$ cutoff given the exploratory nature of the study, and the relatively small number of subjects). The results of the McNemar test for equality of modes (pre vs. during) are displayed in Table 8 with significant ($p<.2$) results highlighted. From Table 8 it is again apparent that most of the significant changes in laryngeal function are observed during high pitch voice tasks. Within these tasks—glottic closure pattern, and glottic gap size, axial rotation, petiole deviation— all seemed to change from pre- to during-block. Also, with the exception of the high pitch sniff task, none of the vocal fold mobility tasks evidenced significant changes in function using these mode data.

Although the omnibus chi-square analysis identified many significant changes, the majority of parameters (according to task) were not found by the mode analysis to reveal any significant pre- to during-block change among the subjects (see Table 8.). In other cases, the chi-square analysis identified a significant difference, and the McNemar test was also significant ($p<.2$); however, close inspection of the changes in the distribution of subjects failed to identify any clear or consistent patterns of change. In other words, the subjects changed from normal in the precondition to abnormal during the block, but the direction of change in ratings was not consistent among all subjects. For instance, in the case of axial rotation, instead of all subjects changing in the same manner during the block (i.e., all subjects rated as showing axial rotation to the left during the block), rather, there was an unclear or inconsistent pattern of change (i.e., some subjects showed left rotation and other subjects showed right rotation). Thus, following close inspection of the modal data, the following task parameters did not reveal any clear pattern of change despite evidencing significant change at the McNemar level: (1) Normal Pitch Normal Volume (NPNV) - Axial rotation of the larynx; (2) Glissando Up

Table 8. Percentage of subjects with normal rating before and during nerve block according to task and item based on the MODE analysis.

	Normal Pitch Tasks				High Pitch Tasks							
	NPNV		NPLV		HPNV		GUNV		HPLV		GULV	
Item	B	D	B	D	B	D	B	D	B	D	B	D
Glottic Closure Pattern	60%	70%	89%	67%	20%	50%	44%	67%	22%	56%	33%	78%
Vertical Level of Vocal Fold	100%	100%	100%	100%	100%	90%	100%	100%	100%	100%	100%	100%
Size of Glottic Gap	70%	60%	89%	67%	20%	60%	33%	67%	33%	67%	22%	67%
Bowed Vocal Fold	100%	100%	100%	100%	100%	90%	100%	100%	100%	100%	100%	100%
Length of Vocal Folds	---	---	---	---	100%	100%	100%	100%	100%	89%	100%	100%
Vibratory Behavior: Right	100%	100%	100%	100%	90%	90%	100%	89%	100%	100%	100%	100%
Left	100%	100%	100%	100%	90%	100%	100%	89%	100%	100%	100%	100%
Phase Symmetry	90%	80%	78%	78%	80%	70%	89%	89%	100%	78%	89%	67%
Supraglottic Activity	40%	40%	22%	22%	50%	40%	33%	11%	33%	22%	11%	22%
Aryepiglottic Fold Length	90%	90%	100%	89%	90%	80%	100%	78%	100%	100%	89%	78%
Axial Rotation of the Larynx	90%	80%	89%	56%	70%	50%	100%	33%	89%	67%	67%	78%
Petiole of the Epiglottis	90%	90%	89%	89%	100%	70%	100%	56%	100%	67%	100%	78%

B=Before block D=During block

Table 8 continued

	Mobility Task		Sniff Tasks					
	HEE		NP Sniff		HP Sniff		Whistle	
Item	B	D	B	D	B	D	B	D
Vocal Fold Mobility: Right VF	100%	90%	100%	100%	100%	88%	67%	67%
Left VF	90%	100%	88%	100%	100%	75%	78%	78%
Sluggishness /Vocal Fold Lag: Right VF	80%	90%	88%	100%	100%	88%	100%	100%
Left VF	90%	100%	100%	88%	100%	75%	100%	100%
Symmetry of Vocal Fold Movements	60%	80%	75%	63%	100%	50%	78%	89%
Vocal Fold Edge Shape: Right VF	100%	100%	100%	100%	100%	100%	100%	100%
Left VF	100%	100%	100%	88%	100%	88%	100%	89%
Supraglottic Activity	70%	70%	38%	63%	75%	75%	---	---
Axial Rotation of the Larynx	---	---	75%	75%	100%	50%	---	---

B=Before block D=During block

Highlighted values significant at the 0.2 level.

Normal Volume (GUNV) - Aryepiglottic fold length and axial rotation of the larynx. The remaining task parameters were shown by chi-square Analysis, McNemar test, and subsequent mode analysis to reveal fairly consistent pattern of changes. They are discussed in detail below.

High Pitch Normal Volume

Following the aforementioned analyses, the High Pitch Normal Volume task revealed consistent patterns of change for glottic closure pattern, size of glottic gap, and the petiole of the epiglottis. As shown in Table 9, consistent *improvement* in glottic closure was observed from pre- to during-block during this task, with 3 more subjects (5 total) having a complete closure pattern *during* the block than in the preblock condition. As a result of improved glottic closure pattern, the size of the glottic gap also consistently improved, with 3 additional subjects (5 total) in the during block condition having complete closure (Table 10). Table 11 reveals a consistent deviation of the petiole of the epiglottis to the *right* (i.e., to the side of CT paralysis) during the block for this and three other tasks. Before the block, all 10 subjects had a centered petiole, and during the block 4 were rated with a right-sided deviation.

Table 9. Changes in glottic closure pattern by task.

		Glottic Closure Pattern					
TASK		Complete Closure	Anterior Chink	Posterior Chink	Spindle Shape	Hourglass Shape	Incomplete Closure
HPNV	pre-	20%	0%	30%	20%	0%	30%
	during	50%	0%	20%	10%	0%	20%
HPLV	pre-	22%	0%	67%	0%	11%	0%
	during	56%	0%	44%	0%	0%	0%
GULV	pre-	33%	0%	67%	0%	0%	0%
	during	78%	0%	22%	0%	0%	0%

Table 10. Changes in size of glottic gap by task.

TASK		Size of Glottic Gap: None	Mild	Moderate	Severe
HPNV	pre-	30%	70%	0%	0%
	during	50%	50%	0%	0%
GUNV	pre-	33%	67%	0%	0%
	during	67%	33%	0%	0%
HPLV	pre-	33%	67%	0%	0%
	during	67%	33%	0%	0%
GULV	pre-	22%	67%	11%	0%
	during	67%	33%	0%	0%

Table 11. Changes of the petiole of the epiglottis by task.

TASK		Epiglottic Petiole Deviation: No Deviation	Deviation to the left	Deviation to the right
GUNV	pre-	100%	0%	0%
	during	56%	0%	44%
HPNV	pre-	100%	0%	0%
	during	60%	0%	40%
HPLV	pre-	100%	0%	0%
	during	67%	0%	33%
GULV	pre-	100%	0%	0%
	during	78%	0%	22%

Glissando Up Normal Volume

During the block, the size of glottic gap also improved during Glissando Up Normal Volume, as shown in Table 10. Before the block, 3 of 9 subjects were rated as having no glottic gap, whereas during the block, 6 subjects received a rating of no glottic gap. A consistent pattern of petiole deviation to the right was once again observed (Table 11). Of 9 subjects, who all received a normal/centered rating of the petiole in the preblock condition, 4 were rated as having a deviated petiole to the right during the block while producing Glissando Up Normal Volume.

High Pitch Loud Volume

As shown in Tables 9, 10, and 11, High Pitch Loud Volume revealed consistent changes in glottic closure pattern, size of glottic gap, and the petiole of the epiglottis. Five of 9 subjects (up from 3 of 9) during the block were rated with a complete glottic closure, while 6 of 9 (3 of 9 preblock) were rated with no glottic gap. All 9 subjects rated with a midline petiole before the block, and 3 of 9 deviated to the right during the block. High Pitch Loud Volume also revealed a consistent pattern of phase asymmetry, which was found to be significant and consistent by the chi-square analysis, McNemar test, and subsequent mode analysis. All 9 subjects were rated as having symmetrical vocal fold movement in the preblock state, whereas only 2 subjects were asymmetrical during the block.

Glissando Up Loud Volume

Consistent with previously discussed tasks, Glissando Up Loud Volume revealed significant and consistent changes in glottic closure pattern, size of glottic gap, and the petiole of the epiglottis (Tables 9, 10, & 11). This task identified the most significant improvement in glottic closure during the block. Three of 9 subjects had a complete closure pattern before the block, whereas during the block, 7 subjects showed complete closure. Two subjects had glottic gap prior to the block, and 6 had complete closure during the block. Petiole deviation was also consistent to the right. Two of 7 subjects rotated to the right during the block, whereas all subjects were observed to display a midline petiole prior to the block.

Although 4 of 9 subjects were identified by the judges as showing the epiglottic deviation pattern, data from one subject (i.e., M01) was missing for the GUNV task due to technical problems related to equipment failure. When the rating data from M01's HPNV production were inspected, they confirmed the identical pattern of deviation of the petiole to the side of weakness (see Figure 4). This task is very similar to GUNV. Furthermore, inspecting the remaining subjects for subtle petiole deviation confirmed that one other subject showed a similar pattern, which was not identified by the judges. Thus, it appears that 6 of 10 subjects displayed the petiole deviation pattern, and the results for pre- and during-block are shown in Figures 4 thru 9.

<u>High Pitch Sniff</u>

Upon inspection of the mode data, the only task to reveal a consistent pattern of change in regards to axial rotation of the larynx was High Pitch Sniff, despite two other tasks (i.e., GUNV, NPLV) which also showed a change pre- to during block as indicated by the chi-square analysis and McNemar test (Table 12). In the case of GUNV and NPLV, there was no consistent pattern identified upon closer inspection of the actual modal data. However, in the case of HP Sniff, there was a consistent finding of rotation of the posterior commissure to the left and anterior commissure to the right) during the block. All 8 subjects were rated as having no rotation preceding the block, while half of the subjects showed evidence of posterior commissure rotation to the left during the block, contradicting the currently held view that unilateral ESLN denervation produces anterior commissure deviation to the intact side. High Pitch Sniff also revealed consistent patterns of change regarding mobility of the left vocal fold, sluggishness of the

a. b.

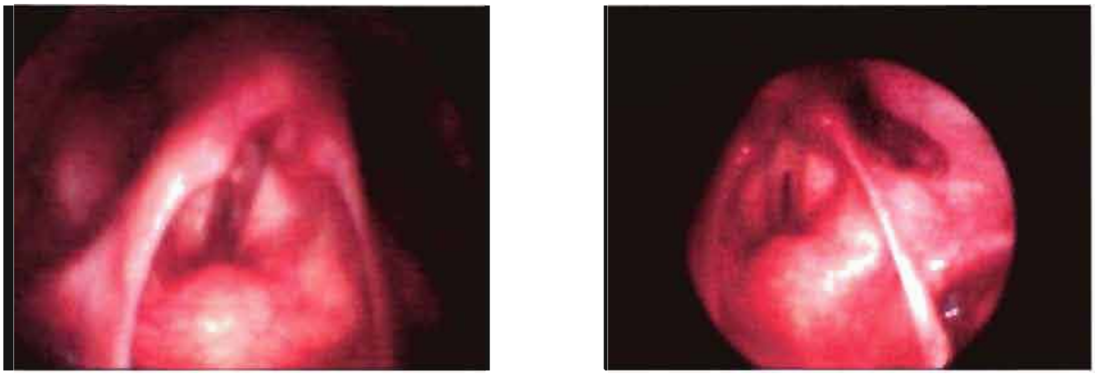


Figure 4. Changes in petiole position from pre- to during block subject M01. a) Preblock HPNV; b) During block HPNV

a. b.

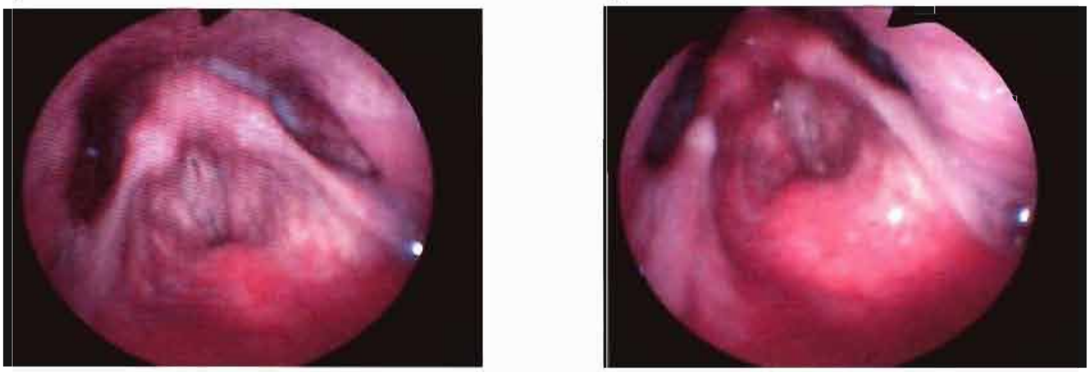


Figure 5. Changes in petiole position from pre- to during block subject M02. a) Preblock GUNV; b) During block GUNV

a. b.

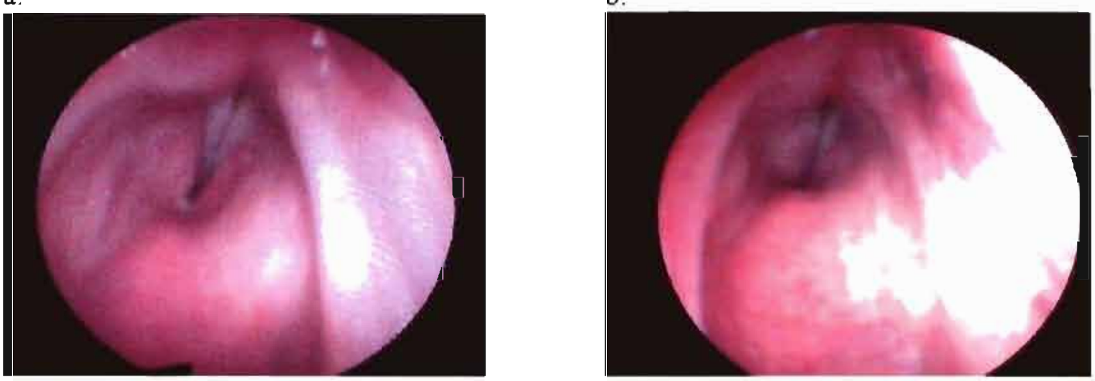


Figure 6. Changes in petiole position from pre- to during block subject M04. a) Preblock GUNV; b) During block GUNV

a. b.

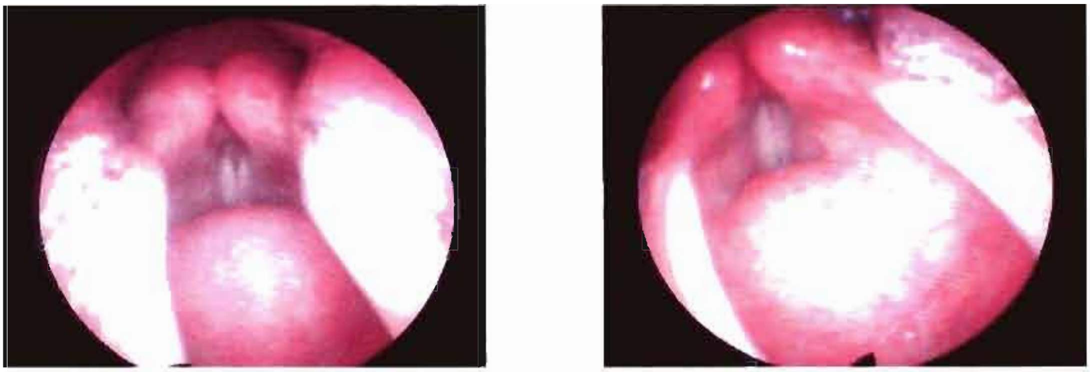


Figure 7. Changes in petiole position from pre- to during block subject M05. a) Preblock GUNV; b) During block GUNV

a. b.

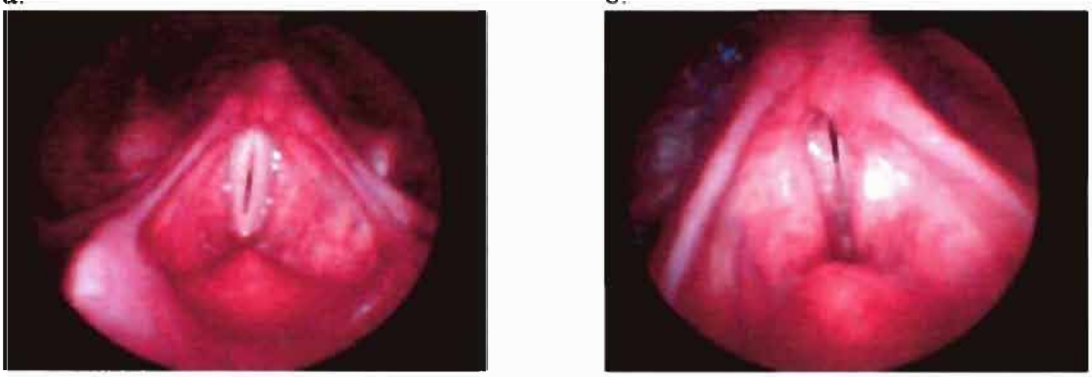


Figure 8. Changes in petiole position from pre- to during block subject M09. a) Preblock GUNV; b) During block GUNV

a. b.

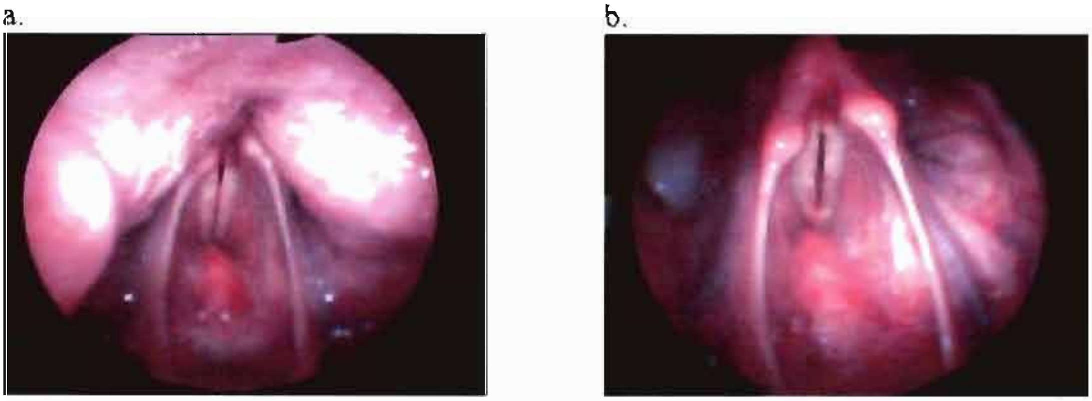


Figure 9. Changes in petiole position from pre- to during block subject M10. a) Preblock GUNV; b) During block GUNV

Table 12. Changes in axial rotation of the larynx by task.

		Axial Rotation of the Larynx		
TASK		No Rotation	PC Left AC Right	PC Right AC Left
NPLV	pre-	89%	11%	0%
	during	56%	33%	11%
GUNV	pre-	100%	0%	0%
	during	33%	33%	33%
HP SNIFF	pre-	100%	0%	0%
	during	50%	50%	0%

left vocal fold, and symmetry of vocal fold movements, all of which go hand in hand. For all three of these parameters, each of the 8 subjects was rated as normal prior to the nerve block, with 2 subjects rated as having partial immobility of the left fold during the block and the same number were rated as having a mild sluggishness of the left fold. Symmetry of vocal fold movements was more apparent during the block, with only 4 of the 8 subject modes indicating asymmetry.

DISCUSSION

The purpose of this investigation was threefold: (1) To examine whether hypomobility of one or both of the vocal folds was associated with unilateral CT paralysis; (2) To examine whether canting (i.e., axial rotation) of the larynx during high pitch production was a marker of ESLN paralysis; and (3) To identify a set of laryngeal tasks that maximally provoke or expose SLN dysfunction when present.

Vocal Fold Hypomobility

Four vocal fold mobility tasks were performed by each subject in an attempt to fatigue the vocal folds and assess the presence of any vocal fold motion impairment, including vocal fold hypomobility, during a block of the ESLN (ddK "hee," Normal Pitch Sniff, High Pitch Sniff, & Whistle). No consistent patterns of vocal fold hypomobility (i.e., sluggishness, reduced ab- or adduction, or asymmetry) were observed across any of these tasks. Despite numerous tasks to provoke and explore vocal fold motion impairment, the only evidence of hypomobility occurred during one task (High Pitch Sniff), where only 2 subjects were rated with mild hypomobility and mild sluggishness of the left fold (i.e., the fold contralateral to the side of weakness). From these findings, it seems that hypomobility/sluggishness of one or both folds is not a reliable marker of acute ESLN paralysis, which supports Heman-Ackah and Barr's (2006) assertion that a paretic nerve cannot be identified accurately through a muscle pattern of hypomobility. These results are in stark contrast with earlier work by Rubin et al., (2005) who identified ipsilateral vocal fold sluggishness during repetitive phonatory tasks as the definitive feature of ELSN paresis or paralysis. In addition, it is also worth noting that some of our vocally normal subjects were actually rated as having a hypomobile fold prior to the block, although no hypomobility was observed during the block. Similarly, there were subjects who received identical abnormal ratings during both the pre- and during-block conditions (see Appendix D). These findings of hypomobility occur within individuals who had no history of past or present voice problems and, thus, consideration should be given to the possibility that some hypomobility or asymmetry in vocal fold movement may in fact, represent a previously unappreciated variation of normal, and not necessarily evidence of neuropathology.

Laryngeal Rotation

Axial rotation of the larynx was examined during nine tasks produced by the subjects (with the exception of the whistle task). In almost all tasks, including all of the high pitch voice production tasks, no consistent pattern of axial rotation emerged. Thus, based upon the absence of a consistent finding across high pitch voice tasks, axial rotation of the larynx should not be considered a pathognomonic feature of ESLN paralysis. In only one task, however (High Pitch Sniff), did a pattern of axial rotation surface, and in only one-half of the subjects studied. In contrast to the currently accepted model of ESLN paralysis which involves rotation of the anterior commissure to the intact CT side (i.e., the left side in this study) and the posterior commissure to the weakened side (i.e., the right), our results showed the opposite pattern with rotation of the posterior commissure to the left. Abelson and Tucker (1981) discussed the mechanics associated with possible patterns of rotation: "If the cricoid cartilage remained fixed during contraction of the cricothyroid muscle, the thyroid cartilage would rotate such that the anterior commissure would be displaced towards the paralyzed side. If the thyroid cartilage was fixed and the cricoid moved, on the other hand, the posterior commissure would be displaced toward the paralyzed side" (p. 468). The High Pitch Sniff task was specifically included in this study not just to evaluate vocal fold movement, but because it provides a unique opportunity to observe the larynx elevate from a neutral or lowered position (during inhalation) to an elevated and tensed position, as the subject quickly transitions into a high pitched /i/ production. The absolute extent and dynamic nature of the laryngeal movement involved in the production of this task may have contributed to the more consistently observed rotation pattern. This HP Sniff maneuver deserves further consideration as a possible clinical test for unilateral CT paralysis.

Which Tasks Expose ESLN Dysfunction?

Following multiple levels of examination of the data, high pitch voice tasks were found to most reliably and efficiently reveal dysfunction associated with unilateral ESLN paralysis, which is not surprising given the function of the CT as a vocal fold tensor. Evidence for high pitch voice tasks as being particularly revealing of CT dysfunction is found in both the parametric and nonparametric rating data. For instance, the overall rating of the larynx, a visual analog scale, changed significantly from pre- to during-block conditions during all high pitch tasks, with raters consistently rating the larynx's appearance and function as more abnormal during the block condition. Notably, these changes were all greater during high pitch voice tasks as compared to any observed during voice produced at normal pitch. Furthermore, the chi-square analysis and the subsequent McNemar tests also confirmed the sensitivity of high pitch voice tasks in revealing ESLN paralysis by identifying several significant changes observed in subjects during the nerve block. Moreover, of all the high pitch tasks, Glissando Up Normal Volume appeared to be the most revealing of ESLN-related dysfunction.

Specific markers or parameters were also identified that were consistent across multiple high pitch tasks. The most robust and reliable marker was deviation of the petiole of the epiglottis. This was observed to consistently deviate to the right during four of the five high pitch tasks (see Table 10), which were all confirmed to be significant by the chi-square analysis and McNemar test. Petiole deviation to the right was observed during the fifth high pitch task as well, but was not found to be statistically significant. This finding has not been reported elsewhere in the literature and appears to reflect asymmetric CT function that causes deviation of the petiole to the side of weakness. The biomechanics of such epiglottic deviation are not immediately apparent and deserve future consideration. They do not appear to be related to deviation of the anterior commissure, however.

A surprising finding from this investigation was the improvement of glottic closure and glottic gap during the block. It has been asserted that mild glottic insufficiency is a result of ESLN paresis or paralysis, with bowing of the affected fold, and decreased longitudinal tension. Statistically significant change of glottic closure toward complete closure was observed during three tasks, and reduction of the size of glottic gap was observed through four (see Tables 8 and 9). Thus, glottic closure patterns following the block were not associated with increased incompetence. It may be that other intrinsic and extrinsic laryngeal muscles hyperfunction immediately in response to CT weakness, and this compensation occurs very rapidly.

As discussed above, axial rotation of the posterior commissure to the left was significant during production of High Pitch Sniff. However, this parameter was not consistent across multiple tasks. Other parameters previously discussed, that have been asserted to be markers of ESLN paralysis include a shortened vocal fold (i.e., reduced longitudinal tension), bowing of the ipsilateral fold, vocal fold plane differences, and aryepiglottic fold asymmetry were not found to be significantly different when comparing pre- to during-block conditions (see Tables 6 and 7).

Lidocaine-induced Paralysis

Valid questions surround the precision of lidocaine-induced paralysis to model selective ESLN damage only. One limitation of the model relates to the possibility that lidocaine may have diffused into and/or infiltrated surrounding ipsilateral extrinsic laryngeal muscles (i.e., sternothyroid m. or sternohyoid m.) or nerves, and the possibility that selective ESLN block could not be achieved without possibly affecting surrounding muscles. By extension, the salient features identified in this study would then represent the cumulative effects of ESLN dysfunction as well as any regional extrinsic muscle dysfunction. While this is possible, the muscles that presumably could have been blocked in the vicinity of the injection site include the sternothyroid m., whose principal action is to draw the thyroid cartilage downward, and less likely, because of its medial position— the sternohyoid— whose principal action is to draw the hyoid bone downward, and fix the hyoid bone when the lower jaw is opened against resistance. If these muscles were truly affected by the lidocaine, it is difficult to reconcile how the two specific laryngeal findings identified in this study, i.e., petiole deviation and axial rotation during HP Sniff, could be explained by selective dysfunction of these two muscles observed during high pitch voice production tasks, exclusively. So, none of the signs that we identified during high pitch vocal tasks (and associated laryngeal elevation), could be explained merely as reflecting unilateral sternothyroid or sternohyoid dysfunction.

The lidocaine-induced paralysis may not necessarily replicate the mechanism of injury and repair seen clinically in the subacute and chronic stages of neural recovery. There may be functional differences between lidocaine-induced CT paralysis versus what happens clinically when the nerve is damaged via surgical or nonsurgical trauma (i.e., nerve sectioning, stretching, or compression) or alternatively via infectious processes (i.e., viral-related injury), especially during the postacute phase. Although acute, unilateral CT paralysis should manifest similarly regardless of the etiology (i.e., lidocaine-induced vs. surgical denervation), there is a need to validate that the lidocaine-block induced dysfunction observed in this study (i.e., petiole deviation on Glissando Up and axial rotation on High Pitch Sniff) is observed in clinical examples of verified denervation related to trauma or other etiologies.

Related to the above, the lidocaine-induced CT paralysis model employed here attempts to model the effects of *acute* denervation, and it is possible that such a model differs substantially from what would be seen clinically in cases of chronic denervation wherein compensatory muscle activation patterns may be observed. However, without understanding the acute effects of unilateral CT denervation, it is impossible to distinguish immediate effects from any later effects presumably related to adaptive or maladaptive compensatory patterns. Only by understanding the effects of acute dysfunction can any inferences be made regarding the degree or need for compensation. Thus, subtracting the acute effects observed here from the laryngeal manifestations observed clinically in cases of chronic ESLN denervation, we can eventually disambiguate what manifestations reflect compensation vs. the pure effects of unilateral CT dysfunction.

Conclusions

From this preliminary study modeling the laryngeal manifestations of ESLN denervation, we may conclude that neither vocal fold hypomobility nor axial rotation of the larynx may be considered pathognomonic features. High pitch tasks have been particularly enlightening in contrast to normal pitch tasks at revealing laryngeal dysfunction. Deviation of the petiole of the epiglottis to the affected side was the most consistent marker observed throughout the high pitch tasks. However, if petiole deviation is truly a marker of unilateral CT paralysis, then there is a need to better understand the possible biomechanics underlying such a finding through further research. There is also a need to assess other subjects, females especially. It is not known whether females with CT dysfunction would show similar patterns as observed in the male subjects.

APPENDIX A

STROBOSCOPIC PROTOCOL

SLN Lidocaine Block

Flexible Videolaryngostroboscopy

Participant ID # **Gender: M / F** **Date:**

Testing Session (Check One):

__ Baseline (LEMG electrodes in place) __ During Block (Paralysis)

Instructions/; It is important that complete A-P views of the membranous portion of the vocal folds are video-recorded for each task and the audio is recorded so that the examiner can be heard giving the instructions to the participant. With the anterior commissure at the 6:00 o'clock position on the screen, have the participant sustain /i/ for 2 seconds (or, if unable, as long as possible). Pitch glides should be held at the lowest and highest pitches for at least 2 seconds (and can include falsetto and fry). Be sure to get one good capture of each task.

Sustained Tasks:

1. First, at a comfortable volume, say /i/ using:

1.1 Comfortable pitch _____

2.1 Lowest pitch _____

2.3 Highest pitch _____

2.4 Glissando up _____

2.5 Glissando down _____

2. Next, with a very soft voice, say /i/ using:

2.1 Comfortable pitch _____

2.2 Lowest pitch _____

2.3 Highest pitch _____

2.4 Glissando up _____

2.5 Glissando down _____

3. Next, with a loud voice, say /i/ using:

3.1 Comfortable pitch _____

3.2 Lowest pitch _____

3.3 Highest pitch _____

3.4 Glissando up _____

3.5 Glissando down _____

Repetitive Phonatory Tasks:

4. Next, take in a deep breath and repeat /i/ at a comfortable loudness, as rapidly and steadily as you can, for at least 7 seconds or until I tell you to stop (demonstrate laryngeal DDKs):

4.1 Comfortable pitch _____

4.2 Lowest pitch _____

4.3 Highest pitch _____

5. Next, take in a deep breath and repeat /hi/ at a comfortable loudness for at least 7 seconds or until I tell you to stop.

5.1 Comfortable pitch _____

5.2 Lowest pitch _____

5.3 Highest pitch _____

6. Next, take in a deep breath and repeat /pi/ at a comfortable loudness for at least 7 seconds or until I tell you to stop.

6.1 Comfortable pitch _____

6.2 Lowest pitch _____

6.3 Highest _____

7. Next, repeat the following sequence...sniff then say /i/ briefly...5 times (demonstrate):

7.1 Comfortable pitch _____

7.2 Lowest pitch _____

7.3 Highest pitch _____

8. Finally, check laryngeal adductor response by gently touching L. aryepiglottic fold with scope tip and R. aryepiglottic fold with scope tip.

8.1 Left _____

8.2 Right _____

APPENDIX B

INSTRUCTIONS TO RATERS

PLEASE READ CAREFULLY

It is imperative that you read these instructions completely and carefully before proceeding to the rating forms. As you know this study aims to evaluate the laryngeal effects of acute ESLN denervation using FVLS recordings. Ten vocally normal, young adult males were recorded before and during unilateral ESLN block. A wide variety of voice and laryngeal tasks/conditions were sampled to evaluate possible effects of unilateral CT dysfunction. In your packet, you will find 3 CDs labeled Disc 1, 2, and 3, and a series of rating forms. Each CD contains video files to be played using Windows Media Player. On each CD, files are labeled according to a specific voice or laryngeal task (e.g., Normal Pitch Normal Loudness, High Pitch Loud Voice, whistle happy birthday, sniff "ee" etc.). For all video files, each participant's pre- and during-block FVLS samples are presented as a set (i.e., sample A and B). However, the order is randomized, and you are blinded to whether sample A or B represents the pre or during-block recording for that participant. Furthermore, the order of participants is also randomized across the various video files. **Each CD contains many video files, but you will be responsible for rating <u>only</u> a subset of those files. It is important to rate <u>only</u> the video files that are identified on the front page of the rating forms!!!**

Each set of rating forms has a front page identifying the CD number (disc 1, 2 or 3) which contains the video file to be rated, the filename of the specific video file, and a brief description of the voice condition/task corresponding to that file (e.g., Normal Pitch Normal Loudness- voice produced at normal pitch and normal loudness). You should know that the many parameters included on the rating forms were selected based upon features that had been previously reported as possible diagnostic markers of unilateral ESLN denervation. We have attempted to streamline the rating process by creating categorical ratings for each parameter. You are asked to circle the rating that most closely reflects your judgment of the parameter of interest. Because you are one of twelve raters, we have provided operational definitions for each of the laryngeal parameters to improve consistency within and across judges.

LARYNGOSCOPIC PARAMETERS AND THEIR DEFINITIONS

RATING OF SPECIFIC VIDEO FILES CONTAINED ON DISC 1 AND DISC 3 REQUIRES JUDGMENTS OF THE FOLLOWING PARAMETERS...

(1) Glottic closure pattern-description of vocal fold approximation during adduction or maximum vocal fold closure (i.e., maximum closed phase of the vibratory cycle). The "dominant" closure pattern is rated and the types include:

Complete- Vocal folds completely oppose along their entire length.

Anterior Glottic Gap (Chink)-Occurs when the VFs fail to oppose along some point of the anterior third of their length, in the presence of complete closure posterior to that point.

Posterior Glottic Gap (Chink)-observed when the VFs oppose along the membranous portion with a persistent gap remaining at the posterior glottis (including arytenoid body area).

Spindle-shape (bowed vocal folds)-gap along the length of the membranous portion of the VF in the presence of vocal process approximation.

Hourglass-vocal folds oppose along the mid-membranous portion of the VF, but fail to approximate anterior and posterior to the mid-membranous portion.

Incomplete-inability to completely oppose the VF along their entire length (including vocal processes).

(2) Size of Glottic gap-general judgment of the extent to which the vocal folds fail to approximate during phonation (i.e., the maximum closed phase of the vibratory cycle) with reference to the following parameters: (a) width of the glottic gap-a measure of the latero-medial involvement of the gap, (b) length of the glottic gap-measure of the antero-posterior involvement of the gap. The size of the glottal gap represents a composite rating of the width and length of the gap, and is rated from "None" or No gap to "Severe" gap.

(3) Vertical level of VF approximation-general judgment of whether the vocal folds meet at the same glottic plane level during adduction. If both vocal folds meet on plane during adduction this is rated as "On plane". If one vocal fold is closing at a higher or lower level this is rated as "Off Plane."

(4) Bowed Vocal Fold- During maximum vocal fold closure, a judgment is made whether one vocal fold edge is bowed, i.e., the free edge of the membranous vocal fold is displaced outward in the medio-lateral dimension in the presence of vocal process approximation. This parameter is rated as either "None", "Left" VF Bowed, or "Right" VF Bowed.

(5) Length of Vocal Folds: During maximum vocal fold closure, the visible length of each vocal fold is estimated to determine whether asymmetries in length are observed. This estimated length includes where the vocal folds extend from their insertion at the thyroid notch to the base of the arytenoid cartilages. Ratings include symmetrical (equal) length, left vf shorter, right vf shorter.

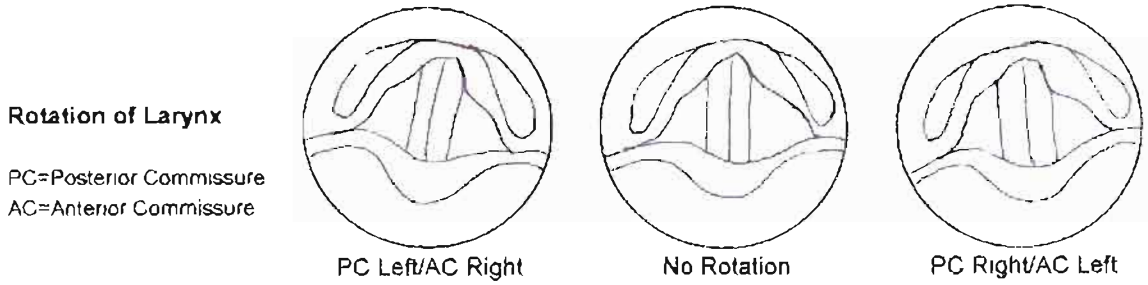
(6) Vibratory Behavior: This is a composite rating of three stroboscopic parameters: amplitude of vibration, mucosal wave, and non-vibrating portions. It is understood that independent ratings of these parameters may be difficult with FVLS. Therefore, this scale represents a general rating/judgment of the vibratory normalcy of the left and right vocal fold considering the demands of the voice task. Because these ratings are highly dependent on the target pitch and loudness characteristics of the voice (i.e, high pitch vs. normal pitch, loud volume vs. normal volume), ratings such as "reduced" or "absent" should be reserved for clearly abnormal findings, and not for normal variations on the basis of target pitch or loudness characteristics. The rater should consider (1) the amplitude of vibration i.e., the extent to which the vocal fold edge is displaced outward in the medial-lateral dimension, (2) the mucosal wave i.e., the presence of a traveling wave observed in the vertical dimension caused by the displacement of the mucosa overlying the body or muscle, and (3) non-vibrating portions i.e, any adynamic segments observed within the body of the vocal folds where the vocal folds fails to oscillate. Ratings are assigned for each vocal fold independently, and range from normal, reduced, to absent vibratory behavior.

(7) Phase Symmetry-general judgment of the extent to which the vocal folds move as mirror images of each other in the timing of opening, closing, and closure. This is assessed during sustained oscillation/vibration. Raters will provide an estimate of whether the true vocal folds move symmetrically or asymmetrically.

(8) Supraglottic Activity- general judgment of the extent to which the supraglottic structures such as aryepiglottic folds, epiglottis, and ventricular folds show significant displacement from their normal resting position. This represents a composite judgment of reduced or compromised view of the true vocal folds in the latero-medial and antero-posterior dimensions. In the A-P dimension, the arytenoids may be displaced towards the epiglottis, the epiglottis or petiole may be retracted towards the arytenoid complex or both patterns may be present. In the L-M dimension, the ventricular folds may be seen to approach the midline during phonation or meet during phonation. The degree of supraglottic activity is assessed as None, Mild, Moderate or Severe. Furthermore, if ventricular fold activity is present, the rater is asked to determine whether it is primarily symmetrical, or whether it is asymmetrical with left ventricular fold constriction greater than the right (i.e., Left>Right) or right ventricular fold constriction greater than the left (i.e, Right>Left).

(9) Aryepiglottic Fold Length- a general judgment regarding the extent to which the length of the aryepiglottic folds are judged to be equal or symmetrical during maximum vocal fold closure/adduction. Asymmetries should be recorded as Left A.E. fold shorter, or Right A.E. fold shorter.

(10) Rotation of the Larynx: Axial rotation of the larynx during phonation whereby there is canting of the glottis from the normal midline position at rest (i.e., an asymmetric lateral shift of the anterior or posterior larynx away from midline creating an oblique glottis during phonation). The presence of axial rotation is rated during maximum vocal fold closure. The various ratings are illustrated in the following diagram.



(11) Petiole of the Epiglottis- the extent of deviation of the epiglottic petiole (i.e., lateral shift of the petiole) from midline is judged during maximum vocal fold closure. The petiole of the epiglottis is judged in relation to the anterior commissure. Is the petiole in the center of the anterior commissure, or does it deviate to the left or to the right of the anterior commissure?

(12) Overall Rating of the Larynx: by placing a vertical slash on this visual analog scale, the rater estimates the extent to which he/she believes the larynx appears to be functioning "normally" within the context of the voicing task demands. This is a composite rating of form and function, and should reflect the rater's overall impression regarding the normalcy of form and function, **without** regard to the quality or loudness characteristics of the voice. The rater is encouraged to only consider laryngeal form and function, and ignore auditory-perceptual cues.

****RATING OF SPECIFIC VIDEO FILES CONTAINED ON DISC 2 REQUIRE JUDGMENTS OF THE FOLLOWING PARAMETERS...NO STROBOSCOPIC PARAMETERS ARE RATED AS THESE SAMPLES ARE VIEWED IN OBSERVATION LIGHT ONLY, AND INVOLVE RATINGS OF VOCAL FOLD MOBILITY AND POSITION PRIMARILY.**

(1) Vocal Fold Mobility (extent of ab-/adduction)-a general assessment of the capacity of the vocal folds to abduct and adduct completely. For the purpose of this rating scale, vocal fold mobility is a measure of the <u>degree</u> or <u>extent</u> of abduction (extent of vocal fold lateralization away from the midline) or adduction (extent of vocal fold movement toward the midline). This is <u>not</u> a measure of <u>speed</u> of vocal fold movement, rather it is a measure of <u>extent</u> of movement. If the extent of ab-/adduction is considered within normal limits it is rated as normal, if the extent of ab-/adduction is incomplete it is rated as "partial immobility", and if there is no visible ab-/adduction (complete absence of movement) it is rated as complete immobility.

(2) Sluggishness/Vocal Fold Lag during ab-/adduction: the presence of delayed or sluggish movement of one VF during ab- or adduction (i.e., vocal fold lag). This assesses the relative speed of vocal fold movement and whether a phase lag exists between the vocal folds during ab-/adduction.

(3) Symmetry of Vocal Fold Movements (ab-/adduction): related to items (1) and (2) above, this parameter evaluates the extent to which the vocal folds behave like mirror images during ab- and adduction. The rater is asked to provide

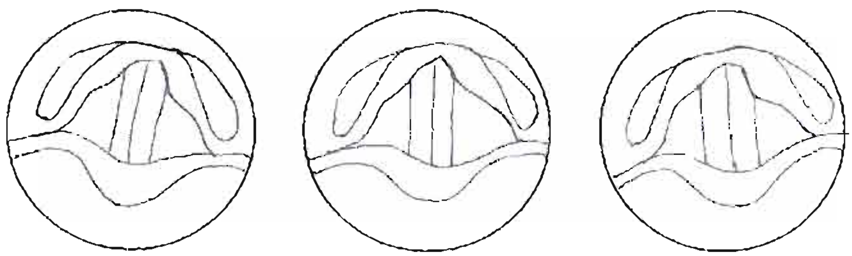
(4) Vocal fold Edge Shape-assessed for each vocal fold side during complete abduction and is related to the straightness of the leading edge. Evaluated as straight or bowed.

(5) Supraglottic Activity during repeated "ee" or "hee" productions- general judgment of the extent to which the supraglottic structures such as aryepiglottic folds, epiglottis, and ventricular folds show significant displacement from their normal resting position during the repeated "ee" or "hee" portions of the production. This represents a composite judgment of reduced or compromised view of the true vocal folds in the latero-medial and antero-posterior dimensions. In the A-P dimension, the arytenoids may be displaced towards the epiglottis, the epiglottis or petiole may be retracted towards the arytenoid complex or both patterns may be present. In the L-M dimension, the ventricular folds may be seen to approach the midline during phonation or meet during phonation. The degree of supraglottic activity is assessed as None, Mild, Moderate or Severe. Furthermore, if ventricular fold activity is present, the rater is asked to determine whether it is primarily symmetrical, or whether it is asymmetrical with left ventricular fold constriction greater than the right (i.e., Left>Right) or the right ventricular fold constriction greater than the left (i.e, Right>Left).

(6) Rotation of the Larynx during the repeated "ee or hee" portion of the productions: Axial rotation of the larynx during phonation whereby there is canting of the glottis from the normal midline position at rest (i.e., an asymmetric lateral shift of the anterior or posterior larynx away from midline creating an oblique glottis during phonation). The presence of axial rotation is rated during maximum vocal fold closure. The various ratings are illustrated in the following diagram.

Rotation of Larynx

PC=Posterior Commissure
AC=Anterior Commissure



PC Left/AC Right — No Rotation — PC Right/AC Left

(7) Overall Rating of the Larynx: by placing a vertical slash on this visual analog scale, the rater estimates the extent to which he/she believes the larynx appears to be functioning "normally" within the context of the voicing task demands. This is a composite rating of form and function, and should reflect the rater's overall impression regarding the normalcy of form and function, **without** regard to the quality or loudness characteristics of the voice. The rater is encouraged to only consider laryngeal form and function, and ignore auditory-perceptual cues.

IMPORTANT STEPS PRIOR TO MAKING RATINGS

(1) Before making any ratings, watch at least the first 3 sets of samples for each video file to orient you to the specific task, the duration of the samples, and the parameters contained on the rating forms. This brief orientation period is an important part of the rating protocol. It will help to familiarize you with the video samples prior to attempting to make formal ratings. You will find that the pre- and during block samples are of relatively short but equal duration, and occur in fairly rapid succession. During this orientation time, it is useful to make adjustments to the size of the viewing window within Windows Media Player to accommodate your own viewing preferences.

(2) Ratings for Disc 1 and 3 require assessment of multiple parameters, which by necessity will require you to pause and rewind the player often. It may be useful to watch both sample A and B for a particular set prior to rendering any ratings, rewind the video, and then begin the process of pausing the samples and rendering ratings for each sample. You are permitted to view the samples as often as necessary to make final ratings.

(3) Because of viewing angle, movement artifact or other reasons, occasionally some parameters will be difficult or impossible to assess. In this case, the rater should circle the "normal" function, rather than leaving the rating blank.

(4) Admittedly, the ratings for discs 1 and 3 demand considerable cognitive energy. To avoid rater fatigue, it is advisable to complete ratings for one or two files at a time, rather than attempting to complete all files over one extended marathon session.

(5) You will be required to rate 10 files corresponding to 10 different voice/laryngeal tasks. The CDs and the associated filenames to be rated are listed below.

DISC 1: Files to Rate
Normal Pitch Normal Volume
Normal Pitch Loud Voice
High Pitch Normal Loudness
Glissando Up Normal Loudness

DISC 2: Files to Rate
Normal Pitch DDK hee
Normal Pitch Sniff ee
High Pitch Sniff ee
Whistle

DISC 3: Files to Rate
High Pitch Loud Voice
Glissando Up Loud Voice

ONCE ALL RATINGS ARE COMPLETED PLEASE INSERT THE RATING FORMS IN THE POSTAGE PAID ENVELOPE AND MAIL. IT IS NOT NECESSARY TO RETURN THE CDS.

THANK YOU AGAIN FOR AGREEING TO COMPLETE THESE RATINGS. YOUR PARTICIPATION IS CRITICAL TO THE SUCCESS OF THIS RESEARCH ENDEAVOR.

APPENDIX C

RATING FORMS

Ratings for Normal Pitch Normal Volume and Normal Pitch Loud Volume

Glottic Closure Pattern: Complete Anterior Chink Posterior Chink Spindle Hourglass Incomplete

Vertical Level of Vocal Fold Approximation: On Plane Off Plane

Size of Glottic Gap: None Mild Moderate Severe

Bowed Vocal Fold (during maximum closure): None Left Right

Length of Vocal Folds: Symmetrical Left Shorter Right Shorter

Vibratory Behavior: Composite of Mucosal Wave/Amplitude of Vibration
Right: Normal Reduced Absent
Left: Normal Reduced Absent

Phase Symmetry: Symmetrical Asymmetrical

Supraglottic Activity (i.e., Mediolateral and/or A-P Compression): None Mild Moderate Severe
If supraglottic (false fold) activity is present, is it?: Symmetrical Left>Right Right>Left

Aryepiglottic Fold Length (during closure): Symmetrical Left Shorter Right Shorter

Rotation of the Larynx: No clear rotation PC to Left & Ant. Comm. Right PC to Right & Ant. Comm. Left

Petiole of the Epiglottis: Center Deviates Left Deviates Right

Overall Rating of the Larynx:
Please place a vertical slash mark along the line to indicate how you would describe the function of this larynx.

Normal ____ Profoundly Abnormal

Ratings for High Pitch Normal Volume, High Pitch Loud Volume, Glissando Up Normal Volume, and Glissando Up Loud Volume

Glottic Closure Pattern: Complete Anterior Chink Posterior Chink Spindle Hourglass Incomplete

Vertical Level of Vocal Fold Approximation: On Plane Off Plane

Size of Glottic Gap: None Mild Moderate Severe

Bowed Vocal Fold (during maximum closure): None Left Right

Length of Vocal Folds: Symmetrical Left Shorter Right Shorter

Vibratory Behavior: Composite of Mucosal Wave/Amplitude of Vibration
Right: Normal Reduced Absent
Left: Normal Reduced Absent

Phase Symmetry: Symmetrical Asymmetrical

Supraglottic Activity (i.e., Mediolateral and/or A-P Compression): None Mild Moderate Severe
If supraglottic (false fold) activity is present, is it?: Symmetrical Left>Right Right>Left

Aryepiglottic Fold Length (during closure): Symmetrical Left Shorter Right Shorter

Rotation of the Larynx: No clear rotation PC to Left & Ant. Comm. Right PC to Right & Ant. Comm. Left

Petiole of the Epiglottis: Center Deviates Left Deviates Right

Overall Rating of the Larynx:
Please place a vertical slash mark along the line to indicate how you would describe the function of this larynx.

Normal ____ Profoundly Abnormal

Ratings for Normal Pitch DDK "hee"

Vocal Fold Mobility (extent of ab-/adduction):
Right VF: Normal Mobility Partial Immobility Complete Immobility
Left VF: Normal Mobility Partial Immobility Complete Immobility

Sluggishness/Vocal Fold Lag during ab-/adduction:
Right VF: None Mild Moderate Severe
Left VF: None Mild Moderate Severe

Symmetry of Vocal Fold Movements (ab-/adduction): Symmetrical Asymmetrical

Supraglottic Activity (i.e., Mediolateral and/or A-P Compression): None Mild Moderate Severe
If supraglottic (false fold) activity is present, is it?: Symmetrical Left>Right Right>Left

Vocal Fold Edge Shape (during abduction):
Right VF: Straight Bowed
Left VF: Straight Bowed

Overall Rating of the Larynx:
Please place a vertical slash mark along the line to indicate how you would describe the function of this larynx.

Normal ____ Profoundly Abnormal

Ratings for Normal Pitch Sniff "ee" and High Pitch Sniff "ee"

Vocal Fold Mobility (extent of ab-/adduction):
Right VF: Normal Mobility Partial Immobility Complete Immobility
Left VF: Normal Mobility Partial Immobility Complete Immobility

Sluggishness/Vocal Fold Lag during ab-/adduction:
Right VF: None Mild Moderate Severe
Left VF: None Mild Moderate Severe

Symmetry of Vocal Fold Movements (ab-/adduction): Symmetrical Asymmetrical

Vocal Fold Edge Shape (during abduction):
Right VF: Straight Bowed
Left VF: Straight Bowed

Supraglottic Activity during "ee" (i.e., Mediolateral and/or A-P Compression): None Mild Moderate Severe
If supraglottic (false fold) activity is present, is it?: Symmetrical Left>Right Right>Left

Rotation of the Larynx : No clear rotation PC to Left & Ant. Comm. Right PC to Right & Ant. Comm. Left

Overall Rating of the Larynx:
Please place a vertical slash mark along the line to indicate how you would describe the function of this larynx.

Normal ____ Profoundly Abnormal

Ratings for Whistle

Vocal Fold Mobility (extent of ab-/adduction):

Right VF:	Normal Mobility	Partial Immobility	Complete Immobility
Left VF:	Normal Mobility	Partial Immobility	Complete Immobility

Sluggishness/Vocal Fold Lag during ab-/adduction:

Right VF:	None	Mild	Moderate	Severe
Left VF:	None	Mild	Moderate	Severe

Symmetry of Vocal Fold Movements (ab-/adduction): Symmetrical Asymmetrical

Vocal Fold Edge Shape (during abduction):

Right VF:	Straight	Bowed
Left VF:	Straight	Bowed

Overall Rating of the Larynx:
Please place a vertical slash mark along the line to indicate how you would describe the function of this larynx.

Normal ____ Profoundly Abnormal

APPENDIX D

SUBJECT RATINGS

Appendix D is included as a data file on a disc attached to the inside cover of this manuscript. It contains tables of all subject ratings given during this study.

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