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SOUND CATEGORIES AND NASALANCE SCORE TYPES AFFECTED IN SPEAKERS WITH DYSARTHRIA SECONDARY TO ALS

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ABSTRACT

Purpose: This study aimed to identify the speech sound category and nasalance score type that is most affected in individuals with ALS to aid in evaluation and monitoring of the disease.

Methods: Twenty-three individuals with dysarthria secondary to ALS and 22 healthy aging speakers participated as speakers. Participants with ALS were divided into mild and severe groups based on their speaking rate. Nasalance scores were collected from them using a revised version of the Simplified Nasometric Assessment Procedures (SNAP) test. The nasalance scores were examined against speech intelligibility and speaking rate, and between groups. Perceptual nasality ratings were collected from 20 listeners based on the Rainbow Passage which was recorded from each of the speakers with dysarthria.

Results: The nasalance scores were significantly and positively correlated with perceptual rating of nasality; and significantly and negatively correlated with speech intelligibility and speaking rate. The mild and severe groups showed significant group differences, but the mild and control groups did not. The sibilant was the only sound category that showed significant group differences across nasalance score types.

Discussion: Nasalance is a valid estimation of perception of nasality. Sibilants performed well across nasalance score types, particularly the maximum nasalance score. We suspect this to be the case because of the sustained, airtight closure necessary for their production, and the measurement of the maximum nasalance score.

Key words: amyotrophic lateral sclerosis (ALS), dysarthria, sound category, nasalance score type, sibilant

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Chapter 1

Introduction

Amyotrophic lateral sclerosis (ALS) is a degenerative motor neuron disease in which motor neurons gradually lose function as the disease progresses. There are two types of onset in ALS: spinal and bulbar. In spinal onset, the initial signs of the disease are the loss of motor control of the limbs, and in bulbar onset, the initial signs are the loss of motor control used for swallowing and speech. The decline in functioning of speech organs results in decreased speech intelligibility and quality of speech, which continue to decline until the individual with ALS eventually loses speech completely regardless of onset type (Kent et al., 1991; Saunders, Walsh, Smith, & Teller, 1981).

The speech function decline in individuals with ALS impacts their quality of life significantly. Felgoise, Zaccheo, Duff, and Simmons (2015) retrospectively studied the quality of life of individuals with ALS. Using their functional speech score from the ALS Functional Rating Scale, they found that individuals with mild speech impairment or no functional use of speech had a lower quality of life score than individuals with no speech impairment based on their scores on the ALS Specific Quality of Life questionnaire.

Dysarthria in ALS

The speech disorder in individuals with ALS is dysarthria, a type of motor speech disorder that results from impaired movement of the speech mechanism. The speech mechanism consists of multiple subsystems: articulatory, velopharyngeal, laryngeal, and respiratory subsystems. Rong et al. (2015) examined the contribution of each subsystem to speech intelligibility in individuals with ALS. The results indicated that the primary contributor to speech intelligibility is the articulatory subsystem, and the velopharyngeal (VP) subsystem was the secondary contributor to speech intelligibility. Dysarthria leads to VP dysfunction because it impacts the coupling of velopharyngeal structures. This results in increased nasality and decreased speech intelligibility. Unlike the articulatory subsystem, there is limited knowledge available about VP dysfunction associated with ALS.

Nasalance as a VP Dysfunction Measure

VP dysfunction causes incomplete closure of the VP port and results in increased airflow through the nasal cavity. In other words, VP dysfunction increases nasality of speech. Nasality is a perceptual measure, but can be quantified using various approaches such as nasal airflow and nasalance. Nasalance has been one of the common approaches for measuring nasality. Nasalance is the ratio of nasal acoustic energy to oral and nasal acoustic energy measured by a nasometer (Kummer, 2014). Larger nasalance scores indicate greater amount of acoustic energy from the nasal cavity compared to the oral cavity. It is an efficient and convenient instrumental approach and has been widely used in clinical settings. Previous studies have shown that nasalance is a valid representation of nasality (Dalston, Warren, & Dalston, 1991; Watterson, Lewis, & Deutsch, 1998). Watterson et al. (1998) showed that nasalance data hold reasonable sensitivity and specificity when distinguishing between typical and hypernasal speech regardless of the speech stimuli types. In addition, nasalance data showed good sensitivity and specificity when distinguishing between typical and hyponasal speech (Dalston et al., 1991). Thus, nasalance is a valid representation of nasality related to resonance disorders.

Nasalance Score Types

The nasalance analyses from the nasometer software provide various types of nasalance information. These include nasalance fluctuation in each time interval. Based on these values, simple statistics are obtained such as average, minimum, and maximum values. The most frequently used variable is the average value, which shows the mean nasalance score across the speech stimuli. The norm values of nasalance scores are based on mean values of speech materials. In addition, clinical interpretation of VP dysfunction based on nasalance scores is based upon the mean values. For example, two standard deviation above the mean would indicate hypernasality (Kummer, 2005). The minimum nasalance value is the score when the least amount of acoustic energy was detected from the nasal cavity in relation to the oral cavity. Individuals with ALS have increased nasality from limited control of VP function rather than structural differences (e.g., oronasal fistura). Therefore, the minimum nasalance value likely represents when the velopharyngeal port is smallest or the closure is tightest during production of speech stimuli. The maximum nasalance value likely represents when the velopharyngeal port is most open. Therefore, each value represents a different velopharyngeal configuration in individuals with ALS. Considering that dysarthria in ALS results in reduced control of the speech subsystem, it is unclear which of the aforementioned values would be most representative of VP dysfunction in ALS.

Nasalance by Sound Category

Nasalance scores vary depending on speech sound because of differing acoustic impedance in the VP area during production across sounds. Depending on the specific sound, more open or closed VP configuration is necessary for the sound to be produced. For instance, in typically aging speakers, oral sounds require complete decoupling of the VP structures in order to be produced correctly, while for nasal sounds, the VP structures must be completely coupled.

Thorp, Virnik, and Stepp (2013) measured the nasalance scores of typically aging adults for nasal and nonnasal syllables and sentences, using varying types of vowels in each stimulus, and found the nasalance scores differed by stimuli characteristics including vowel types, nasalization conditions, and place of articulation. Lewis, Watterson, and Quint (2000) studied individuals without VP dysfunction (non-VPD) and individuals with VP dysfunction (VPD), and measured the nasalance scores of syllable and sentence stimuli that were controlled for vowel type. In both groups, the nasalance scores differed by speech sound, but the differences became greater and showed its own pattern in people with VPD, showing that different stimuli present a different amount sensitivity to VP dysfunction.

It is clear nasalance scores differ by speech sound, but it is unclear which speech sound is most sensitive to VP dysfunction in ALS. Bell-Berti (1993) found that specifically oral consonants require a more closed VP configuration than nasal consonants and vowels. Speech sounds requiring a tighter seal of the VP port tend to be produced with higher nasalance scores by individuals with VP dysfunction, and this is not the case in typical speakers (Lewis et al., 2000).

VP dysfunction can be divided into VP insufficiency (structural defect), VP incompetence (neurophysiological disorders), and VP mislearning (Kummer, 2014). Previous studies in VP insufficiency showed that, among oral sounds, sibilants and plosives tend to be most vulnerable in individuals with cleft palate. There is, however, not agreement among studies whether sibilants or plosives are more vulnerable to the effect of VP insufficiency. Isshiki, Honjow, and Morimoto (1966) suggests that plosives are more affected, but McWilliams (1958), Subtelny and Subtelny (1959), and Spriesterbach, Darley, and Rouse (1956) suggest that sibilants are more affected with plosives trailing closely behind.

Individuals with ALS experience VP incompetence which has been investigated much less than VP insufficiency. The current study focuses on VP incompetence, and it remains unknown which consonant category is most influenced in individuals with this type of VP dysfunction. More understanding about this VP dysfunction will aid in understanding its impact on speech intelligibility.

Purpose of the Study

The purpose of this study is to find the most effective measure of nasalance in individuals with ALS for evaluation and monitoring of the disease. Our study will investigate three questions related to nasalance in individuals with ALS. (1) Do nasalance scores of all sound categories have the same level of sensitivity to the presence and severity of dysarthria in individuals with ALS? (2) Do minimum, average, and maximum nasalance scores of sound categories have the same level of sensitivity to the presence and severity of dysarthria in individuals with ALS? (3) Are there nasalance scores of specific sound categories that are more sensitive to the presence and severity of dysarthria in individuals with ALS?

This study predicts that nasalance scores for different sound categories have different sensitivity to the presence of dysarthria in individuals with ALS. Previous research (McWilliams, 1958; Subtelny & Subtelny, 1959; Spriesterbach et al., 1956; Isshiki, Honjow, & Morimoto, 1966) suggests that sibilants and plosives show good sensitivity to VP insufficiency, so we predict that sibilants and plosives will show good sensitivity to VP incompetence, as well. In regards to the second and third research questions, we cannot make a prediction due to the lack of literature in these areas.

Chapter 2

Methods

Participants: Speakers

This study involved two groups of speakers: a group of 23 individuals with dysarthria secondary to ALS and a control group of 22 typically aging speakers. The speakers with dysarthria were recruited from the Penn State Hershey ALS Clinic and Research Center. Each of these speakers met the Revised El Escorial criteria for definite, probable, probable laboratory-supported, or possible ALS (Brooks, Miller, Swash, Munsat, 2000). In this group, there were 11 males and 12 females with ages ranging from 43 to 80 (M=63.13; SD=8.93). The characteristics of the speakers with ALS are shown in Table 1. Included in this table are speakers' scores from the ALS Functional Rating Scale-Revised (ALSFRS-R), a questionnaire asked of individuals with ALS that is used to gauge their physical functioning as the disease progresses. Twelve areas of functioning are rated by the individuals on a scale of 0 (lowest functioning) to 4 (highest functioning). Table 1 displays the speakers' bulbar sub-score and total score. The ALSFRS-R bulbar sub-score is the sum of the three scores related to bulbar function (speech, salivation, and swallowing). The total score is the sum of the sub-scores from each section of the questionnaire, and it shows overall functioning of the person with ALS (Cedarbaum et al, 1999).

Individuals with ALS were assigned to two severity groups based on speaking rate. Speaking rate is used in addition to speech intelligibility to gauge severity of dysarthria in individuals with ALS. Previous research suggests that speaking rate declines are highly correlated with speech intelligibility declines; individuals with ALS present with speech intelligibility decline when they reach 100-120 words per minute (wpm) speaking rate (Ball, Willis, Buekelman, & Pattee, 2001; Ball, Beukelman, & Pattee, 2002; Yorkston, Strand, Miller, Hillel, Smith, 1993). For the purposes of our study, 110 wpm served as the severity cutoff between groups of speakers. Speakers with a speaking rate higher than 110 wpm were placed in the mild group, and speakers with a speaking rate lower than 110 wpm were placed in the severe group. The mild group was made up of seven speakers with a group average of 126 wpm (SD=5). The severe group was made up of 16 speakers with a group average of 81 wpm (SD=19).

The control group was comprised of 10 males and 12 females with ages ranging from 47 to 80 (M=62.95; SD= 7.35). They were matched to the speakers with dysarthria for gender and age within 5 years. The youngest male, typically aging control speaker was the gender and age match for two of the speakers with dysarthria, ALS14 and ALS19. The typically aging speakers were required to pass a pure tone hearing screening at 30dB in their better ear. Twenty-one of the speakers passed. One of the male typically aging speakers, who was 80 years old, required the use of his hearing aids to pass. All of the speakers' native language was American English, and none of the speakers had any known neurological or speech/language disorders.

Participants: Listeners

In order to be considered to participate in the study, the listeners were required to be 18-40 years of age, a native speaker of American English only, free of any neurological or speech disorders, and inexperienced in communicating with people that have motor speech disorders. In addition, each listener was required to pass a hearing screening, including frequencies, 250, 500, 1000, 2000, and 4000 Hz at 25dB. There were 18 females and 2 males with ages ranging from 18-23 (M= 20.90 ; SD= 1.07).

Procedures: Speech Production

Speakers produced Sentence Intelligibility Test (SIT) sentences, and using this data, SIT and speaking rate were collected as a part of a larger scaled study (Beukelman, Yorkston, Hakel, & Dorsey, 2007). The SIT data for each speaker is also shown in Table 1.

Each of the participants in both groups of speakers were asked to read the Rainbow Passage. The Rainbow Passage is a paragraph that includes all of the phonemes used in Standard American English. It is commonly used by professionals in the field of speech and language to assess individual's speech intelligibility. As the participants read the passage, their speech was recorded. The audio recordings were used for the perceptual nasality ratings.

Nasalance scores were collected for the speakers. All of the scores were collected using a Nasometer (KayPentax), a device used for measuring the nasalance of an individual's speech. The stimuli used to measure the nasalance scores were adapted from the Picture Cued Subtest from the Simplified Nasometric Assessment Procedures (SNAP) test (Kummer, 2005). For the purposes of this study, an adapted version of the test was used so that the stimuli could be used across speakers regardless of severity of dysarthria. Five stimulus sentences from the Picture Cued Subtest were chosen. Each were phonetically balanced and representative of a consonant category (bilabial, alveolar, velar, sibilant, and nasal): "pick up the baby," "take a teddy," "go get a cookie," "Susie sees the scissors," and "mama made some mittens," respectively. The sentence was modeled to each speaker, and they were asked to repeat the sentence. Nasalance scores were measured by the Nasometer as the speaker repeated the sentence. The average, minimum, and maximum values were extracted from the program.

Procedures: Perceptual Rating of Nasality

The recordings of the speakers reading the Rainbow Passage were used to collect perceptual nasality ratings from the listeners. Prior to the task, the following instructions were provided to each listener: “In this task, you will be listening to 23 speakers read a passage. After each passage, you will be asked to rate the hypernasality of the speaker. A person who is “hypernasal” sounds like they are speaking through their nose. You will listen to the full passage and then rate the speaker on a sliding scale from “normal” to “severe hypernasality”. You can move the slider anywhere along the scale that you think is appropriate. You can only listen to each speaker once.” To provide further clarity to the listener’s understanding of the task, the listeners were also provided with audio examples of speakers with mild to moderate, moderate, and severe hypernasality. These audio samples were taken from the American Cleft Palate Craniofacial Association. The listener was then instructed: “Our study includes people that have other speech issues along with hypernasality. When rating the speakers, make sure to rate their nasality, not the clarity of their speech.” Then, the listeners were provided with audio examples to demonstrate this. The examples were of “someone who has other speech issues, but no hypernasality,” and “someone who has other speech issues and substantial hypernasality”. These audio samples were two selected speakers from the current study (ALS7, ALS22 respectively) both producing the speech stimuli, “I say a Ohio again.” These audio samples were used so that listeners were trained to distinguish the difference between hypernasality versus other speech issues (e.g., distorted articulation). Then, the listeners were given an example test which included two audio samples from SIT, also from the current study, that they could practice how to use the visual analog scale (VAS) during the task. They were not provided with feedback on their ratings during the example test or the recorded test.

Perceptual ratings of hypernasality are influenced by the type of rating scale. Previous studies suggest use of a VAS for perceptual judgements of hypernasality results in higher interrater and intrarater reliability and validity of ratings (Baylis, Chapman, Whitehill, Americleft Speech Group, 2015). VASs are influenced by the number of anchors on the scale. Galek and Watterson (2017) showed that providing listeners with three anchors significantly improved interrater and intrarater reliability. Thus, in the current study, three anchors are used on the VAS; Normal, Moderate, and Severe. These are adapted from the labels of anchors in the Consensus Auditory Perception Evaluation-Voice (CAPE-V) (Baylis et al., 2015; Kelchner et al., 2010). The scale ranged from 0-100 with Normal being 0, Moderate being 50, and Severe being 100. The numerical representations were not visible to the listeners during the task. Their rating could be placed anywhere along the scale, meaning it could be any number between 0 and 100. An image of the VAS used by the listeners is pictured in Figure 1. During the task, the listeners were presented with one of the Rainbow Passage audio recordings at a time. After each recording, the listener placed their perceived hypernasality rating of the speaker on our VAS.

Experimental Design and Statistical Analyses

To answer the first and second research questions, two statistical approaches were employed: Pearson correlation coefficients and ROC curve analyses. In these analyses, nasalance of all sound groups as well as types of nasalance scores (minimum, average, and maximum) were tested in individuals with ALS. To answer the third research question, a one-way analysis of variance (ANOVA) was performed comparing three groups: severe, mild, and control. When significant main effect was observed, Tukey post-hoc test was used. The alpha-level of the current study was 0.05.

Chapter 3

Results

Reliability: Perceptual Rating of Nasality

The interrater reliability was identified using the interclass correlation coefficient (ICC). In order to measure the consistency of scores from the raters across the speakers, a two-way mixed model was used. The average ICC was 0.924 which was statistically significant ($p < 0.001$).

Correlates of Nasality Rating

Both speech intelligibility and speaking rate were significantly associated with the perceptual nasality ratings. The correlations for each are -0.512 and -0.566, respectively. These negative correlations show that higher nasality ratings were strongly associated with lower speech intelligibility and speaking rates.

Results for the correlation between nasality ratings and nasalance scores for each sound category revealed significant associations between most of the sound categories. Using 0.75 as a determinant of stronger associations between the variables, the perceptual rating of nasality is strongly associated with average and minimum velar (0.819, 0.787), average and minimum sibilant (0.8, 0.817), and average alveolar (0.773).

Correlates of Speech Intelligibility and Speaking Rate

Results of Pearson correlation coefficient analyses are presented in Table 2. In the following section, the sound categories and nasalance measures that showed significant association are described. All the significant coefficient values (r-values) were negative values indicating that individuals with more severe dysarthria measured by speaking rate and speech intelligibility produced higher nasalance scores.

For the bilabial sounds, a significant association with speech intelligibility was observed in the minimum nasalance score but not in average and maximum nasalance scores. With speaking rate, a significant association was observed in average and minimum nasalance scores. For alveolar sounds, a significant association was observed between speech intelligibility and the minimum nasalance score, but not with the average and maximum nasalance scores. Speaking rate was significantly correlated with all three types of nasalance scores (average, minimum, and maximum). For velar sounds, speech intelligibility was significantly correlated with average nasalance score, but not with minimum or maximum nasalance scores. With speaking rate, all three types of nasalance scores were significantly correlated. For sibilant sounds, a significant association was observed in the minimum and maximum nasalance scores, but not average nasalance scores. With speaking rate, a significant association was observed in all three types of nasalance scores. For nasal sounds, a significant association with speech intelligibility was not observed in any of the nasalance scores. Speaking rate was observed in a significant association with minimum nasalance scores, but not average or maximum nasalance scores.

The average and range of r-values when tested against SIT was mean -0.184, and range -0.610 – 0.097. The average and range of r-values when tested against speaking rate was mean -0.261, and range -0.695 - 0.068. Among all sound categories, sibilants showed the strongest association (SIT r =-0.610; SR r=-0.695)

Between Group Differences

The results of ANOVA analysis tested general differences between the three severity groups: control, mild, and severe. As seen in Table 3, for the bilabial, alveolar, and velar sounds, a significant group difference was observed for the average and minimum nasalance scores. For the sibilant sounds, a significant group difference was found in all three types of nasalance scores. Among the three types of nasalance scores for the sibilant sounds, the maximum score has the highest effect size (0.256; Table 3). For the nasal sounds, a significant group difference was observed only in the minimum nasalance scores.

The Post Hoc tests revealed more specific differences between groups for each sound category and type of nasalance score (Table 4). For bilabial, alveolar, and velar sounds, average nasalance scores could detect the group difference between severe and mild; and severe and control groups. Maximum nasalance score was not found to be sensitive to the group difference in these three sound categories. Unlike the average nasalance score, minimum nasalance score could only detect the difference between the severe and control groups but not between the severe and mild groups. Thus, among these three sound categories, average nasalance score out-performed minimum and maximum nasalance scores for detecting group difference. It should be noted that, among all the sound categories, only the sibilant sound category showed a significant group difference in all three types of nasalance scores. Across all analyses, a significant group difference between mild and control was not observed. For the nasal sound category, the only group difference detected was between the severe and control groups by the minimum nasalance score.

ROC Curve

The sensitivity and specificity of the nasalance scores across the different sound categories were tested. As seen in Table 5, in the severe group, the following variables showed a significant effect: alveolar average, minimum, and maximum; velar minimum; sibilant average and maximum; and nasal minimum. Maximum sibilant showed the largest area under the curve

(0.789). In the Mild group, there were no significant effects observed across the nasalance scores and sound categories.

When tested using a combined group consisting of the severe and mild groups, representing all the participants with ALS, two variables showed significant effects: velar minimum and sibilant maximum. Both velar minimum and sibilant maximum had similar areas under the ROC curve (0.696 and 0.672, respectively). This is shown in Table 6.

Chapter 4

Discussion

This study aimed to answer three questions about how different sound categories and nasalance score types are associated with the severity and presence of dysarthria in individuals with ALS. The hypothesis for our first question suggested that nasalance scores of different sound categories have different sensitivity to dysarthria. This was supported because the data showed differing degrees of association across statistical tests depending on the sound categories. There were not hypotheses for our second and third questions due to the lack of previous literature. The second question was designed to investigate the sensitivity of different nasalance score types, and the third, to investigate whether there are specific types of nasalance scores within certain sound categories that are more sensitive than others. In regard to the second question, the data showed that the degree of association was different depending on the nasalance score type across all of the statistical tests. The data pertaining to the third question was suggestive of stronger relationships between certain types of nasalance scores in specific sound categories than others. The findings are discussed further in detail in the following sections.

The results of our study supported previous literature suggesting that nasalance is a valid representation of nasality. This was shown through significant associations observed between the nasalance scores and nasality ratings in many of the variables. This finding shows that nasalance scores can be used as a valid measure to estimate the perception of nasality.

As stated before there has not been extensive research completed with VP incompetence, and research based on VP insufficiency is inconclusive about the sensitivity of sibilants versus plosives (McWilliams, 1958; Subtelny & Subtelny, 1959; Spriesterbach et al., 1956; Isshiki et al., 1966). The findings from this study suggest that sibilants are the most sensitive sound category to the severity and presence of VP incompetence in individuals with dysarthria. We speculate that this may be due to the demands placed on the VP subsystem during production of a sibilant. For nasalance score type, there was not a definitive answer in the data as there was for sound category. The average nasalance score seems to have performed well across the tests, and particularly in the group comparison tests, showing that it could possibly be more sensitive to VP incompetence than the minimum or maximum nasalance scores. However, it needs to be emphasized that, only for the sibilants, the maximum nasalance score performed better than the average score across tests.

One of main findings in the current study is the sensitivity of the sibilant sound category to VP incompetence in individuals with ALS. Previous literature indicates that all oral sounds, including sibilants and plosives, require airtight VP closure (Thompson, 1978). Kuehn and Moon (1998) showed that fricatives and plosives require a much tighter VP closure than nasals. Also, it was suggested that nasal airflow during the production of oral sounds was not common in typically aging people (Thompson, 1978). Considering that our study included individuals with VP incompetence, this explains why these sound categories were most affected. Although both sound categories require airtight closure, unlike plosives, the production of a sibilant requires sustained airtight closure of the VP port. In other words, when an individual produces a sibilant, they must maintain airtight closure for a longer interval than when producing a plosive. Jongman, Wayland, and Wong (2000) showed in their study that sibilant fricatives require longer closure durations than non-sibilant fricatives, and Byrd (1993) showed that plosives require shorter closure durations. The sibilants’ durations were between 118-178 milliseconds and the plosives’ were between 59-62 milliseconds, showing that the VP port closure is released more quickly in plosives (Jongman et al., 2000; Byrd, 1993). These speculations explain why the sibilants were found to be the most sensitive sound category in our study.

When the sibilant nasalance scores were compared, each of the score types performed well, but the maximum nasalance score was the most sensitive measure across many of the statistical analyses. The maximum nasalance score is measured when the VP port is most open and/or when the greatest amount of acoustic energy is radiated through the nasal cavity in proportion to the oral cavity. Thus, a higher maximum nasalance score in the production of a sibilant indicates a greater breakdown while attempting to achieve or maintain airtight closure. This means the maximum nasalance score of the sibilant would be better at detecting changes in speech due to the presence or progressing severity of dysarthria.

Limitations

The limitations of our study include the small sample size of the participants in the speech production and perceptual ratings tasks. Also, listeners for the perceptual ratings may have experienced listening fatigue during the task. Another limitation of our study is the stimuli adapted from the SNAP test for the speech production task. The sentences used were not controlled for vowels, and nasalance scores were calculated based on the entire phrase. Coarticulation could have influenced the nasalance scores. In order to correct this, the sentences would have to be more closely analyzed. The productions of the consonants within specific sound categories would have to separated, and nasalance scores would need to be calculated based solely on the consonants. Our reasoning for not following this procedure lies in clinical application. It would take a lot of time to do this for every consonant in each of the sentences, and clinicians do not have time to do so for every client. The procedure we followed, although potentially not as accurate, is more applicable in clinical settings.

Clinical Implication

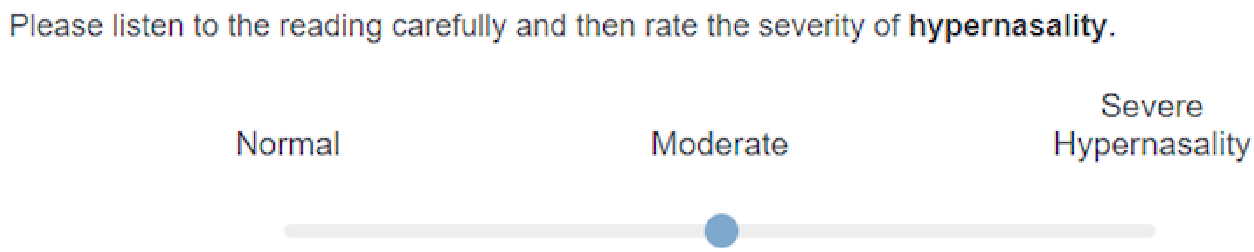
The findings from the current study supported previous literature indicating that the VP subsystem influences SIT significantly in individuals with ALS (Rong et al., 2016). The current study demonstrates how VP dysfunction influences perception of nasality and the contribution that VP dysfunction and its perceptual outcome have on the overall outcome of speech in ALS. Both SIT and SR were strongly and negatively associated with the perceptual ratings of nasality showing the critical role of the VP subsystem.

Overall, the findings suggest that the sibilant maximum nasalance score would be more sensitive than others to the changes in speech production resulting from dysarthria secondary to ALS. As mentioned before, the average nasalance score detected these same changes in speech. In the clinical setting, the average nasalance score is the most widely used score type when considering an individual's VP subsystem. Based on our findings, clinicians may want to consider including the maximum nasalance score of the sibilant for diagnosis and treatment planning as the disease progresses.

Appendix A

Figures

Figure 1. Visual Analog Scale Used for Perceptual Nasality Rating



Appendix B

Tables

Table 1. Characteristics of participants with dysarthria secondary to ALS

ID	Age (yrs)	Sex	ALS Onset Type	Time since Onset of Dysarthria (months)	Severity	ALSFRS-R Bulbar score	ALSFRS-R Total score	Speaking Rate (wpm)	SIT (%)
ALS1	60	M	Bulbar	9	Mild	9	42	202	97.58
ALS2	76	F	Bulbar	18	Mild	9	29	133	97.58
ALS3	80	M	Bulbar	1	Mild	6	37	131	94.85
ALS4	61	F	Mixed	5	Mild	9	29	131	94.55
ALS5	65	M	Bulbar	12	Mild	9	45	126	90.00
ALS6	60	M	Mixed	49	Mild	10	35	124	92.42
ALS7	68	M	Spinal	8	Mild	7	9	118	67.58
ALS8	64	F	Bulbar	15	Severe	9	45	109	91.21
ALS9	64	M	Bulbar	37	Severe	8	44	108	91.82
ALS10	67	M	Mixed	201	Severe	6	23	102	93.64
ALS11	71	F	Bulbar	15	Severe	9	39	94	93.03
ALS12	69	F	Bulbar	20	Severe	7	35	94	71.21
ALS13	70	F	Bulbar	31	Severe	1	36	93	52.73
ALS14	48	M	Spinal	10	Severe	9	34	88	70.30
ALS15	66	F	Bulbar	33	Severe	5	37	83	94.24
ALS16	64	M	Bulbar	51	Severe	6	40	80	79.55
ALS17	66	F	Bulbar	5	Severe	6	32	77	11.52
ALS18	63	F	Spinal	11	Severe	4	12	70	11.82
ALS19	47	M	Mixed	36	Severe	3	24	70	10.00
ALS20	43	F	Spinal	120	Severe	8	24	65	58.79
ALS21	64	F	Bulbar	19	Severe	5	39	57	25.76
ALS22	50	M	Bulbar	16	Severe	9	25	100	42.73
ALS23	66	F	Bulbar	44	Severe	2	20	48	6.67

Table 2. Results of Pearson Correlation Coefficients analyses for speech intelligibility and speaking rate

Sound Category	Nasalance score type	Speech Intelligibility	Speaking Rate
Bilabial	Average	ns	-.415*
	Minimum	-.418*	ns
	Maximum	ns	ns
Alveolar	Average	ns	-.498*
	Minimum	-.507*	-.435*
	Maximum	ns	-.463*
Velar	Average	-.446*	-.424*
	Minimum	ns	ns
	Maximum	ns	ns
Sibilant	Average	ns	-.501*
	Minimum	-.459*	ns
	Maximum	-.610**	-.695**

*. $p < 0.05$

**. $p < 0.01$

ns = not significant

Table 3. Significant results in a one-way analysis of variance (ANOVA) on severity group difference

Sound Category	Nasalance Score Type	df	F	p-value	Effect Size
Bilabial	Average	2, 42	5.688	0.007	0.213
	Minimum	2, 42	3.763	0.031	0.152
Alveolar	Average	2, 42	7.940	0.001	0.274
	Minimum	2, 42	6.335	0.004	0.232
Velar	Average	2, 42	5.721	0.006	0.214
	Minimum	2, 42	4.798	0.013	0.186
Sibilant	Average	2, 42	6.821	0.003	0.245
	Minimum	2, 42	4.132	0.023	0.164
	Maximum	2, 42	7.227	0.002	0.256
Nasal	Minimum	2, 42	4.609	0.016	0.180

Table 4. Post hoc results for between group differences

Sound Category	Nasalance Score Type	Direction of the effect	Mean Difference	p-value
Bilabial	Average	Severe >Mild	17.60	0.028
		Severe > Control	14.22	0.013
	Minimum	Severe > Control	6.17	0.030
Alveolar	Average	Severe > Mild	19.20	0.013
		Severe > Control	17.08	0.002
	Minimum	Severe > Control	7.99	0.003
Velar	Average	Severe > Mild	15.94	0.042
		Severe > Control	14.39	0.009
	Minimum	Severe > Control	10.26	0.011
Sibilant	Average	Severe > Mild	20.52	0.017
		Severe > Control	14.39	0.009
	Minimum	Severe > Control	10.03	0.031
	Maximum	Severe > Mild	26.38	0.013
		Severe > Control	21.78	0.004
Nasal	Minimum	Severe > Control	9.78	0.024

Table 5. ROC curve results for severe group

Sound category	Nasalance Score Type	Area	Standard Error	p-value
Alveolar	Average	.711	.091	0.020
	Minimum	.693	.091	0.034
	Maximum	.706	.089	0.024
Velar	Minimum	.717	.091	0.017
Sibilant	Average	.748	.079	0.006
	Maximum	.789	.070	0.001
Nasal	Minimum	.730	.083	0.012

Table 6. ROC curve results for combined severity groups and control group

Sound Category	Nasalance Score Type	Area	Standard Error	p-value
Velar	Minimum	.696	.082	0.025
Sibilant	Maximum	.672	.082	0.048

BIBLIOGRAPHY

Ball, L. J., Willis, A., Beukelman, D. R., & Pattee, G. L. (2001). A protocol for identification of early bulbar signs in amyotrophic lateral sclerosis. *Journal of the Neurological Sciences,191*(1-2), 43-53. doi:10.1016/s0022-510x(01)00623-2

Baylis, A., PhD., Chapman, K., PhD., & Whitehill, T. L., PhD. (2015). Validity and reliability of visual analog scaling for assessment of hypernasality and audible nasal emission in children with repaired cleft palate. *The Cleft Palate - Craniofacial Journal, 52*(6), 660-670. doi:10.1597/14-040

Bell-Berti, F. (1993). Understanding velic motor control: studies of segmental context. In *Nasals, nasalization, and the velum*(pp. 63-85).

Brooks, B. R., Miller, R. G., Swash, M., & Munsat, T. L. (2000). El Escorial revisited: Revised criteria for the diagnosis of amyotrophic lateral sclerosis. *Amyotrophic Lateral Sclerosis and Other Motor Neuron Disorders, 1*(5), 293-299. doi:10.1080/146608200300079536

Beukelman, D. R., Yorkston, K., Hakel, M. & Dorsey, M. (2007). *Speech Intelligibility Test* (SIT) [Computer Software]. Lincoln, NE: Madonna Rehabilitation Hospital.

Byrd, D. (1993). 54,000 American stops. *UCLA Working Papers in Phonetics, 83*, 97-116.

Carney, P. J., & Sherman, D. (1971). Severity of Nasality in Three Selected Speech Tasks. *Journal of Speech Language and Hearing Research,14*(2), 396. doi:10.1044/jshr.1402.396

Cedarbaum, J. M., Stambler, N., Malta, E., Fuller, C., Hilt, D., Thurmond, B., & Nakanishi, A. (1999). The ALSFRS-R: a revised ALS functional rating scale that incorporates assessments of respiratory function. *Journal of Neurological Sciences,169*(1-2), 13-21. http://dx.doi.org/10.1016/S0022-510X(99)00210-5

Dalston, R. M., Warren, D. W., & Dalston, E. T. (1991). A Preliminary Investigation Concerning the Use of Nasometry in Identifying Patients With Hyponasality and/or Nasal Airway Impairment. *Journal of Speech Language and Hearing Research,34*(1), 11. doi:10.1044/jshr.3401.11

Delorey, R., Leeper, H., & Hudson, A. J. (1999). Measures of Velopharyngeal Functioning in Subgroups of Individuals with Amyotrophic Lateral Sclerosis. *Journal of Medical Speech-Language Pathology,7*, 19-31.

Felgoise, S. H., Zaccheo, V., Duff, J., & Simmons, Z. (2015). Verbal communication impacts quality of life in patients with amyotrophic lateral sclerosis. *Amyotrophic Lateral Sclerosis and Frontotemporal Degeneration,17*(3-4), 179-183. doi:10.3109/21678421.2015.1125499

Galek, K. E., & Watterson, T. (2017). Perceptual anchors and the dispersion of nasality ratings. *The Cleft Palate-Craniofacial Journal*, *54*(4), 423-430.

Isshiki, N. O. B. U. H. I. K. O., Honjow, I., & Morimoto, M. (1968). Effects of velopharyngeal incompetence upon speech. *Cleft Palate J*, *5*, 297-310.

Jongman, A., Wayland, R., & Wong, S. (2000). Acoustic characteristics of English fricatives. *The Journal of the Acoustical Society of America*, *108*(3), 1252-1263.

Kelchner, L. N., Brehm, S. B., Weinrich, B., Middendorf, J., Levin, L., & Elluru, R. (2010). Perceptual evaluation of severe pediatric voice disorders: rater reliability using the consensus auditory perceptual evaluation of voice. *Journal of Voice*, *24*(4), 441-449.

Kent, R. D., Sufit, R. L., Rosenbek, J. C., Kent, J. F., Weismer, G., Martin, R. E., & Brooks, B. R. (1991). Speech deterioration in amyotrophic lateral sclerosis: a case study. *Journal of Speech, Language, and Hearing Research*, *34*(6), 1269-1275.

Kuehn, D. P., & Moon, J. B. (1998). Velopharyngeal closure force and levator veli palatini activation levels in varying phonetic contexts. *Journal of Speech, Language, and Hearing Research*, *41*(1), 51-62.

Kummer, A. W. (2005). Simplified Nasometric Assessment Procedures (SNAP): Nasometer Test-Revised. *Lincoln Park, Kay Elemetrics*.

Kummer, A. W. (2014). *Cleft palate and craniofacial anomalies: effects on speech and resonance*. Australia: Delmar, Cengage Learning.

Lewis, K. E., Watterson, T., & Quint, T. (2000). The Effect of Vowels on Nasalance Scores. *The Cleft Palate-Craniofacial Journal,37*(6), 584-589. doi:10.1597/1545-1569(2000)037<0584:teovon>2.0.co;2

McWilliams, B. J. (1958). Articulation problems of a group of cleft palate adults. *Journal of Speech, Language, and Hearing Research*, *1*(1), 68-74.

Rong P, Yunusova Y, Wang J, Zinman L, Pattee GL, Berry JD, et al. (2016) Predicting Speech Intelligibility Decline in Amyotrophic Lateral Sclerosis Based on the Deterioration of Individual Speech Subsystems. PLoS ONE 11(5): e0154971. doi:10.1371/journal.pone.0154971

Saigusa, H., Yamaguchi, S., Nakamura, T., Komachi, T., Kadosono, O., Ito, H., . . . Niimi, S. (2012). Surgical Improvement of Speech Disorder Caused by Amyotrophic Lateral Sclerosis. *The Tohoku Journal of Experimental Medicine,228*(4), 371-376. doi:10.1620/tjem.228.371

Saunders, C., Walsh, T., Smith, M., & Teller, J. (1981). Hospice care in the motor neurone diseases. *Hospice-The living idea*, 223-235.

Seaver, E. J., Dalston, R. M., Leeper, H. A., & Adams, L. E. (1991). A study of nasometric values for normal nasal resonance. *Journal of Speech, Language, and Hearing Research*, *34*(4), 715-721.

Spriestersbach, D. C., Darley, F. L., & Rouse, V. (1956). Articulation of a group of children with cleft lips and palates. *Journal of Speech and Hearing Disorders*, *21*(4), 436-445.

Subtelny, J. D., & Subtelny, J. D. (1959). Intelligibility and associated physiological factors of cleft palate speakers. *Journal of Speech, Language, and Hearing Research*, *2*(4), 353-360.

Thompson, A. E. (1978). Nasal air flow during normal speech production.

Thorp, E. B., Virnik, B. T., & Stepp, C. E. (2013). Comparison of nasal acceleration and nasalance across vowels. *Journal of Speech, Language, and Hearing Research*, *56*(5), 1476-1484.

Watterson, T., Lewis, K. E., & Deutsch, C. (1998). Nasalance and Nasality in Low Pressure and High Pressure Speech. *The Cleft Palate-Craniofacial Journal,35*(4), 293-298. doi:10.1597/1545-1569(1998)035<0293:nanilp>2.3.co;2

Yorkston, K. M., Spencer, K., Duffy, J., Beukelman, D., Golper, L., Miller, R., . . . Sullivan, M. (2001). Evidence-Based Practice Guidelines for Dysarthria: Management of Velopharyngeal Function. *Journal of Medical Speech-Language Pathology*,*9*(4), 257-274.

ACADEMIC VITA

Academic Vita of Sierra Hobbs
sierrahobbs77@gmail.com

EDUCATION

- The Pennsylvania State University, *University Park, PA*
    - Bachelor of Science in Communication Sciences and Disorders
    - June 2014-May 2018
- The Schreyer Honors College, *University Park, PA*
    - August 2017-Present
    - Thesis title: Sound Categories and Nasalance Score Types Affected in Speakers with Dysarthria Secondary to ALS
    - Thesis supervisor: Ji Min Lee, Ph. D., CCC-SLP

WORK EXPERIENCE

- Springettsbury Township, *York, PA*
    - June-August 2015, 2016, 2017
    - *Park Leader*
        - Communicated with children and parents daily
        - Utilized funds resourcefully and maintained a budget
        - Planned weekly themes and corresponding daily activities
        - Mentored new employees
- Rita's Italian Ice, *York, PA*
    - Summers 2013-2017
    - *Treat Team Member*
        - Communicated with customers and maintained strong customer service
        - Cooperated with employees to prepare products
        - Worked the cash register and handled money
        - Maintained a clean work environment
        - Trained new employees

LEADERSHIP EXPERIENCES

- National Student Speech Language and hearing Association (NSSLHA)
    - August 2014-Present
    - *Secretary (2015-2016), Fundraising Chair (2016-2017)*
        - Communicated with executive board and members of the club
        - Organized fundraising events benefitting Penn State Dance Marathon
        - Volunteered at nursing homes and local literacy events for children
- Health and Human Development Honor Society
    - September 2015-Present

- *Student Council Liaison (2017-2018)*
    - Communicated with members of student council and club about concerns and events in the college
    - Volunteered at blood drives, Friday Night Lights Out, Hartley Wildflower Trail
- Women's Leadership Initiative
  - August 2016-May 2017
  - *Student*
    - Selected by application for a year-long professional development and leadership training class specifically for women

ACADEMIC INVOLVEMENT

- Communication Sciences and Disorders Journal Club
  - September 2016-Present
  - *Member*
    - Present research articles about primary progressive aphasia and dysarthria
    - Critique and read research articles about various field related topics
    - Discuss research with professors and members of the club
- Penn State Dance Marathon (THON) Committee Member
  - October 2015-March 2016
  - *Rules and Regulations Committee Member*
    - Cooperated with other committee members to ensure safety throughout event
    - Enforced rules and monitored spectators and participants during event
  - October 2017-March 2018
  - *Operations Committee Member*
    - Maintained a sanitary environment throughout events
    - Advocated for THON's sustainability mission and goals
    - Cooperated with other committee members throughout the year

RESEARCH & TEACHING

- Speech Production Laboratory
  - January 2017-Present
  - *Laboratory member*
    - Assisted with the reduction of acoustic and kinematic data in Excel
    - Learned about velopharyngeal dysfunction in people with dysarthria secondary to amyotrophic lateral sclerosis
    - Collected perceptual nasality data from listener participants for thesis
- Teaching Assistant
  - January 2016-May 2016
  - *Developmental Considerations in the Assessment and Treatment of Language Disorders*

        - Assisted students with learning course content and completing projects
        - Met with students during weekly office hours
        - Verified completion of students' assignments
    - September 2017-December 2017
    - *First-Year Seminar in Health and Human Development*
        - Communicated with students about grades and general questions/concerns
        - Maintained the grade book
        - Graded weekly assignments and assisted in grading papers and assignments throughout semester

AWARDS

- Dean's List
    - Fall 2014-Present
- Fasola Family Trustee Scholarship
    - The Schreyer Honors College
    - 2016-2017
- Janis Jacobs Study Abroad Fund
    - The Schreyer Honors College
    - Summer 2017
- Lindquist Family Trustee Scholarship
    - The Schreyer Honors College
    - 2017-2018
- Richard Albanus Smith Scholarship
    - The Schreyer Honors College
    - 2017-2018

INTERATIONAL EDUCATION

- The Pennsylvania State University, *London, England*
    - May 2017-June 2017
    - Program: Literary London

CONFERENCES

- American Speech-Language-Hearing Association (ASHA) Convention, *Philadelphia, PA*
    - November 2016
    - *Student Attendee*
        - Attended presentations covering topics including dysphagia, aphasia, dementia, augmentative and alternative communication (AAC), swallowing in the NICU, and stuttering