Effect of Dysphonia and Cognitive-Perceptual Listener Strategies on Speech Intelligibility

*Connie K. Porcaro, †,‡Paul M. Evitts, †Nicole King, †Cassandra Hood, †Erin Campbell, †Layla White, and *Jacqueline Veraguas, *Boca Raton, Florida, and †Towson, and ‡Baltimore, Maryland

ABSTRACT: There is a high prevalence of dysphonia among professional voice users and the impact of the disordered voice on the speaker is well documented. However, there is minimal research on the impact of the disordered voice on the listener. Considering that professional voice users include teachers and air-traffic controllers, among others, it is imperative to determine the impact of a disordered voice on the listener. To address this, the objectives of the current study included: (1) determine whether there are differences in speech intelligibility between individuals with healthy voices and those with dysphonia; (2) understand whether cognitive-perceptual strategies increase speech intelligibility for dysphonic speakers; and (3) determine the relationship between subjective voice quality ratings and speech intelligibility. Sentence stimuli were recorded from 12 speakers with dysphonia and four age- and gender-matched typical, healthy speakers and presented to 129 healthy listeners divided into one of three strategy groups (ie, control, acknowledgement, and listener strategies). Four expert raters also completed a perceptual voice assessment using the Consensus Assessment Perceptual Evaluation of Voice for each speaker. Results indicated that dysphonic voices were significantly less intelligible than healthy voices ($P \leq 0.001$) and the use of cognitive-perceptual strategies provided to the listener did not significantly improve speech intelligibility scores ($P = 0.602$). Using the subjective voice quality ratings, regression analysis found that breathiness was able to predict 41% of the variance associated with number of errors ($P = 0.008$). Overall results of the study suggest that speakers with dysphonia demonstrate reduced speech intelligibility and that providing the listener with specific strategies may not result in improved intelligibility.

Key Words: Dysphonia−Intelligibility−Listener strategies−Cognitive-perceptual−Voice ratings−Voice disorders−Professional voice.

INTRODUCTION

Dysphonia or a disordered voice is a common occurrence for many individuals throughout their lifetime. A gradual increase has been noted from 2008 until 2012 in the prevalence of this diagnosis in the United States.[1] Analysis of the United States 2012 National Health Interview Survey indicated that 1 in 13 adults or 7.6% of the population reported voice problems in the past year.[2] A common trend across prevalence studies is that women are more impacted by voice disorders than men (9.3% versus 5.9%) and that the likelihood of experiencing a voice disorder increases with age.[3−5] Furthermore, a common trend described in prevalence studies indicates that only a minority of individuals who reported voice problems seek treatment, thus further perpetuating the overall problem. Clearly, such high prevalence numbers and the fact that few seek treatment represents a major health care problem.

Large numbers of the workforce in the US hold jobs where voice is a critical factor. Research on voice use tied to employment demonstrates a range from 25%[6] to as high as 45%.[7] Studies of voice use and employment considered many professions, including but not limited to factory workers, clergy, teachers, attorneys, counselors, and performers.[8] More recently, studies have demonstrated that many jobs where voice is highly used result in reported voice disorders. Positions associated with higher than normal reports of voice disorders include university instructors[9−11] fitness instructors,[12,13] air traffic controllers,[14,15] and teachers.[16−20] These professional voice users have reported negative impacts on financial, social, and work performance issues. Teachers have reported reduced activities or interactions,[16] considerable loss of workdays due to voice issues,[19] and less ability to communicate efficiently in the classroom.[19] Studies have also demonstrated that students in classrooms where teachers have dysphonia demonstrate impaired auditory comprehension in understanding their teachers' voices and indicate a negative impact on classroom communication and educational practice.[21,22] Investigation on the impact of impaired voice quality on information processing and perception in a dual-task paradigm revealed that a creaky voice quality interfered with cognitive abilities as noted by decreased secondary task performance and impaired retention of information.[23]

The ability to communicate clearly is important in the workplace as well as in general life situations. Intelligibility is defined as the ability of a listener to recover a speaker's message.[24] It is crucial that individuals with high voice use are intelligible to listeners when they are working. Thus, determination of the impact of dysphonia on speech intelligibility would prove valuable for this population. Listeners

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From the *Department of Communication Sciences and Disorders, Florida Atlantic University, Boca Raton, Florida; †Department of Audiology, Speech-Language Pathology, and Deaf Studies, Towson University, Towson, Maryland; and the ‡Department of Otolaryngology − Head and Neck Surgery, Johns Hopkins School of Medicine, Baltimore, Maryland.

Address correspondence and reprint requests to Connie K. Porcaro, Department of Communication Sciences and Disorders, Florida Atlantic University, PO Box 3091, 777 Glades Road, Boca Raton, FL 33431. E-mail: cporcaro@fau.edu

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receive less phonetically salient information to process when listening to a person with dysphonia.[25] For example, a lack of glottal closure, which is common in many speakers with dysphonia, can result in turbulent noise in the higher frequencies, which may mask the acoustic information needed to differentiate stops, fricatives, and affricates.[26] Overall, these differences may result in reduced intelligibility in speakers with dysphonia compared to those with a healthy voice. Decreased speech intelligibility has been demonstrated in many speaker populations, including people with dysarthria[27−29] people who have undergone a laryngectomy,[30] and individuals with hearing loss.[31,32] The possible impact of dysphonia on speech intelligibility has more recently been investigated, with first efforts occurring specifically in spasmodic dysphonia. A disordered voice source from spasmodic dysphonia results in significantly reduced intelligibility.[33] More recently, Evitts and colleagues[34] examined speech intelligibility of 91 speakers with dysphonia secondary to phonotrauma and found that scores were significantly reduced compared to speakers with nondisordered voices. In addition, Ishikawa and colleagues[35] studied the effects of background noise on dysphonic voice compared to healthy voices. Results indicated that dysphonic voices were significantly less intelligible compared to healthy voices under conditions of background noise. However, the difference in intelligibility between speakers with dysphonia and those with healthy voices was not significant under quiet conditions.

One factor that could potentially influence intelligibility in speakers with dysphonia could be the listener's overall impression of that person's speech or voice quality. Numerous studies have shown that listeners report negative impressions of speakers with Parkinson's disease,[36] vocal nodules,[37] and alaryngeal speech, among others.[38] In an investigation of the effect of voice disorders on college students' judgments of personality and appearance, speakers with voice disorders were judged more negatively than speakers who did not have voice disorders.[39] Interestingly, acknowledging or making a statement about the nature of the communication disorder has been examined as a possible way to overcome these negative listener impressions and potential negative impact on overall speaker intelligibility. For example, Blood and Blood[40] reported that listeners responded more favorably to individuals using alaryngeal speech if the speaker first acknowledged the disorder. Results suggested that acknowledgement of the voice disorder may have ultimately desensitized listeners to the effects of the altered acoustic signal. While intelligibility was not explored, the resultant improvement in listener impressions may have also had an impact on other outcomes, including speech intelligibility. This may be similar to studies showing that increased familiarity results in improved speech intelligibility in speakers with dysarthria.[27−29]

Intelligibility of a speaker is impacted not only by the abilities of the speaker, but also by the listening environment and skills employed by the listener. Listeners use both top−down (prediction) and bottom−up (processing) when comprehending what speakers say.[41] Studies of individuals with speech disorders demonstrate that listeners employ both of these strategies in an attempt to understand an altered speech signal produced by a speaker with dysarthria.[42,43] To shed further light on this, Liss and colleagues[44−46] presented a series of studies aimed at disclosing the cognitive-perceptual processes that listeners employ when presented with a disordered speech signal. Overall, results of the studies highlight the dynamic, bi-directional relationship between the listener and the speaker and that intelligibility can be influenced through means other than manipulating the acoustic signal itself.

Klasner and Yorkston[47] also recognized the value in learning how everyday listeners interact with speakers with reduced intelligibility. Their work resulted in knowledge of what barriers everyday listeners encounter and what strategies they utilized in determining what a speaker with dysarthria was saying. This line of work has demonstrated that listeners employ both bottom−up and top−down strategies to enhance intelligibility, including segmental (eg, listening to sounds without context), suprasegmental (eg, breaking syllables into individual sounds), linguistic (eg, using context to understand words), and cognitive (eg, paying greater attention than usual to the speech). Overall, results showed that listeners used different cognitive-perceptual strategies based on the type of dysarthria presented. Similarly, Hustad and colleagues[48] examined speakers with dysarthria secondary to cerebral palsy and found that listeners endorsed the use of cognitive and linguistic strategies with this population, but there was no significant difference in which strategies were endorsed between speakers with higher versus lower intelligibility scores.

The fact that numerous studies investigating the impact of perceptual strategies of listeners on disordered speech intelligibility only included speakers with dysarthria may be related to the focus on the filter rather than the voicing source.[32] However, Ramig[49] noted that other parameters related to the voicing source (eg, pitch, prosody, voice quality) also play a pivotal role in a speaker's ability to convey their intended message. This finding, coupled with recent data showing reduced speech intelligibility with dysphonic speakers,[34] indicates that further attention is warranted. In fact, no studies to date have examined the use of strategies to improve intelligibility scores in speakers with dysphonia.

Given that many professional voice users experience dysphonia and that one recent study demonstrated that dysphonia may impair intelligibility even under quiet conditions, it is important to further investigate the impact of a disordered voice on the speech signal. It has been indicated by previous research that acknowledging a voice disorder may help the listener by lessening distraction, which leads to the question of whether acknowledgement of dysphonia would improve intelligibility. Since listeners report benefit on intelligibility tasks when strategies are used, it is of interest to learn if strategies can be useful for listeners communicating with individuals with reduced intelligibility secondary to dysphonia. Additionally, the relationship between perception of individual voice parameters (ie, pitch, loudness, quality) could add detail in consideration of intelligibility and listener strategies. The specific questions of this research study include:

1. Is there a difference in speech intelligibility between typical, healthy speakers, and those with dysphonia?
2. What is the impact of providing listeners with cognitive-perceptual strategies to increase speech intelligibility for speakers with dysphonia?
3. What is the relationship between voice quality ratings and measures of speech intelligibility?

MATERIALS AND METHODS

Participants

The two groups of participants in this study included speakers (n = 16) and listeners (n = 129). All participants signed consent forms that had been approved by the Institutional Review Boards at Towson University, Florida Atlantic University, and the Johns Hopkins School of Medicine.

Speakers

Speakers included 12 female speakers diagnosed with dysphonia and four age-matched, nonvoice disordered, healthy female speakers. Median age range was 26.8 years for the speakers with dysphonia and 30.5 years for the healthy female speakers. Age matching was completed by selecting four typical, healthy speakers from a large corpus of recorded stimuli who represented quartile age ranges of the disordered speakers. Thus, ages of the typical, healthy speakers were 19 years, 26 years, 32 years, and 49 years. All spoke English as a first language and reported normal to corrected-to-normal vision necessary for the reading task. Inclusion criteria was ascertained by patient report and investigator observation for all the speakers consisted of being female, between the ages of 18 and 50 years, no history of stroke, brain injury, or hearing loss or other cognitive, speech, or language impairments that might impact intelligibility of speech. Participants over the age of 50 were excluded to ensure that the effects of aging voice did not add an additional variable in this study.[50,51] The overall speaker pool was selected to best represent a large group of professional voice users. Based on recent workforce data from the Bureau of Labor Statistics,[52] a large proportion of professional voice users are teachers, representing 6% of the total US workforce in 2016 and 82% of teachers are female.[53] Finally, the age range was selected and the age range was chosen as approximately 70% of teachers are under 50 years of age.[53]

The voice quality of the typical, healthy speakers was perceptually assessed by two licensed and certified speech-language pathologists with more than 5 years of clinical experience in the area of voice disorders. All were determined to have voice quality within normal range. Individuals with a diagnosis of dysphonia were recruited from the Department of Otolaryngology-Head and Neck Surgery at the Johns Hopkins School of Medicine. Diagnosis among the 12 speakers in this group consisted of dysphonia resulting from vocal nodules, vocal polyps, and/or phonotraumatic behaviors such as secondary muscle tension dysphonia. These speakers were diagnosed as having dysphonia following case history and videostroboscopic examination by board-certified otolaryngologists with specific training in laryngology.

Listeners

A total of 121 listeners, 114 female (mean age= 22.08 years, SD = 3.0, range 19−40 years) and seven male (mean age = 21 years, SD 1.73, range 19−24 years), served as listeners in this study. All listeners met the following inclusion criteria: (a) English as their primary language, (b) no reported current or past learning disability, hearing loss, speech and/or language disorder, or any other injury that affected their cognition or hearing; and (c) normal hearing as assessed by pure tone screening at 20 dB SPH at 500, 1000, 2000, and 4000 Hz.[54] Listeners were recruited from various majors at two universities.

Stimuli

Each speaker was seated in a quiet room with a headset microphone (AKG C-420 III, AKG Acoustics, Vienna, Austria) which was kept at a constant distance of 2 inches from the corner of the mouth. Speakers were instructed to produce the sentences at a comfortable pitch, rate, and loudness level. The audio production was recorded at 48 kHz sampling rate via an acoustic analysis software program (Computerized Speech Laboratory 4500, KayPentax, Montvale, NJ) and saved as a wave file. Stimuli included one phonemically balanced sentence list containing ten sentences from the Hearing in Noise Test (HINT).[55] Sentences ranged from 5−7 words, with an average of 5.7 words. Review of one of the lists revealed an average of 1.3 articles and 4.4 content words per sentence. To reduce the potential effect of familiarity on intelligibility through the repetition of sentence stimuli,[56,57] each speaker produced a unique, preassigned HINT list. Digital editing of the acoustic samples was accomplished using an acoustic analysis software program (Adobe Audition, Adobe Systems, San Jose, CA) which resulted in an individual wave file created for each stimulus. In order to increase consistency among stimuli, the acoustic analysis software program was used to bracket the start and end of each sentence defined as the immediate point of onset or offset of any acoustic energy associated with the stimulus.

Using methods similar to Evitts and colleagues,[34,58] four master lists were created with the HINT sentence stimuli. Each list contained 10 randomly selected sentences from each speaker (16 speakers × 10 = 160 sentence stimuli) along with an additional 10% for intra- and inter-rater reliability, for a total of 176 sentences. There was a 10-second pause inserted between each sentence to allow time for transcription.

Listening procedure

Following signed consent, completion of medical questionnaire and hearing screening, listeners were seated in a sound-treated booth in front of a table with two speakers (Bose Companion 2 Series II, Bose Corporation, Framingham, MA) placed on either side and were randomly placed into one of three groups: control, acknowledgement, and strategies. Listeners in the control group were read the following instructions: “You will hear a series of sentences produced by different speakers. Please write down exactly what you hear on the form in front of you.” Using similar methods as found in Blood and Blood,[40] listeners in the acknowledgement group were instructed, “You are going to hear a series of sentences produced by different speakers. Some of the speakers you will hear have a voice disorder. The medical term for a voice disorder is dysphonia. Dysphonia occurs when a person’s vocal folds or vocal cords do not vibrate or move like they should. For this task, please write down exactly what you hear on the form in front of you.” Finally, based on methods from Klasner and Yorkston,[47] listeners in the strategy group were read the following instructions: “You are going to hear a series of sentences produced by different speakers. The speech and voices you hear may be difficult to understand. Please use the following strategies to help out with the task of understanding them.” At this time, the listener was handed a paper with descriptions of the three strategies and was able to follow along as the examiner read each strategy.

A. Segmental strategy: If the sounds are difficult to understand, try using the other sounds within the word to figure out what the word is.
B. Cognitive strategy: Some of the voices that you’re going to hear may sound distorted. For those voices, try to pay close attention to the words being said.
C. Linguistic strategy: If you’re having a hard time understanding some of the words, try using other words around it to figure out what the words may be.

After reading each strategy, the listener was instructed: “For this task, please write down exactly what you hear on the form in front of you using the strategies we discussed to help you.” Immediately following the listening task, all listeners were asked, “Did you find yourself using any strategies to figure out what the speakers were saying? If yes, can you describe the strategies?” Examiners then recorded the responses of the listeners.

Scoring

Intelligibility for each speaker was determined by counting the number of correctly identified words per sentence and dividing by the total number of words possible for each sentence. The scores from each sentence for each listener were then totaled. A mean score was computed across the participants in each listening group. Synonyms or responses reflecting morphological variations, such as *cat* for *cats*, were considered incorrect. Misspellings (eg, *theif* for *thief)* and homophones (eg, *their* for *they’re* or *rode* for *rowed*) were accepted as correct. Errors were also categorized based on whether the word was an article or a content word.

Voice quality ratings

In addition to the intelligibility task described above, it was also of interest to provide additional insight into the relationship between subjective voice quality ratings and the intelligibility of speakers with dysphonia. Initial data by Evitts and colleagues[34] showed that increased subjective ratings of overall severity and strain were associated with increased intelligibility errors. For this, randomized sentence lists of all 16 speakers (12 speakers with dysphonia and four healthy speakers) were presented to four expert, licensed and certified speech-language pathologists, each with more than 10 years of clinical voice experience. Each expert rater completed a perceptual voice assessment[59] (Consensus Assessment Perceptual Evaluation of Voice [CAPE-V]) for each speaker. Measurements were taken from the CAPE-V using a digital caliper (Avenger Products, Henderson, NV) and were measured in millimeters (mm) ranging from 0 to 100. Subjective ratings from expert listeners rather than naïve were included as the CAPE-V was specifically designed for professionals and it was determined *a priori* that use of expert listeners would increase the clinical utility and ecological validity of the results.

RESULTS

Preliminary analysis

Prior to primary analysis, the data were evaluated in multiple ways to determine the appropriate final data set used to answer the research questions. All statistical analyses utilized a statistical analysis program (IMB SPSS Statistics, version 21).

1. Comparison across intelligibility lists

To ensure there was no difference in the number of speech intelligibility errors across the four randomized lists, a one-way ANOVA was calculated. The one-way ANOVA showed no significant difference across the lists, $F(3, 120) = 1.7$, $P = 0.171$.

2. *Assessment of Intra-and Interlistener agreement on speech intelligibility*

In order to assess listener agreement on speech intelligibility tasks, the stimuli contained a random repetition of 10% of each speakers’ sentences, resulting in an additional 16 sentences to the total number of sentences. Reliability was then calculated using methods similar to Hustad[60] whereas the number of agreements was divided by the number of agreements plus the number of disagreements and then multiplied by 100 for a random 25% of the listeners. Intralistener agreement ranged from 96.9% to 100%, indicating strong support for the use of the intelligibility results in the final data analysis.[60] Interlistener reliability was also calculated using the same formula. Average inter-rater reliability across all listeners was 99.9%. These percentages support the use of the intelligibility data in the final analysis.[60]

3. *Assessment of learning and fatigue effect on listeners*

A one-way ANOVA was utilized to determine if there were a significant difference in the number of errors in the first, middle, and third portions of the listening experiment. Results showed no significant difference across portions, F $(2,86) = 1.947$, $P = 0.149$ indicating no learning nor a fatigue effect was present in listeners.

4. *Assessment of Intrarater and inter-rater reliability for voice quality ratings*

Given the large number of variables (ratings) on the CAPE-V to assess voice quality, there is an increased likelihood of multicollinearity or a possibility that the variables were strongly correlated.[61] Typically, following analysis of a correlation matrix, those variables which were strongly correlated would be combined thus reducing the overall number of variables. However, since the CAPE-V was specifically designed to include those variables (voice quality ratings) and because of its widespread clinical use, the authors did not want to alter its intended use. In addition, expert raters were provided with a folder of 10 sentences produced by each of the speakers in a randomized order. These expert raters were asked to complete a CAPE-V on each of the speakers. Expert raters were also randomly provided with two additional speakers' audio files for inter- and intra-rater reliability purposes. To ensure intra-rater reliability of the expert raters using the CAPE-V, Cronbach's alpha was calculated for CAPE-V ratings from the first and second presentation for two of the speakers. All Cronbach alpha values were >0.875 indicating reliable expert listeners.[54] Reliability in voice ratings on the CAPE-V among the expert listeners was calculated using Cronbach's alpha due to the number of raters (4). Cronbach alpha values range from 0 to 1 with values > 0.7 considered to have acceptable reliability across rating groups and values < 0.6 to have poor reliability.[62] Cronbach alpha values ranged from 0.963 (overall severity) to 0.751 (loudness) with all other CAPE-V measures (roughness, breathy, strain, pitch) falling between those levels. Since all Cronbach's alpha levels for all CAPE-V measures were above established criteria for acceptable reliability, all raters and ratings were included in the final regression data set.

Primary analysis

The following sections contain information on each outcome measure, including a description and the results of all statistical analyses.

1. *Speech intelligibility*

Table 1 illustrates speaker demographic information as well as descriptive statistics concerning speech intelligibility and perceptual evaluation of all speakers. Descriptive results show that the intelligibility of healthy speakers ranged from 91% to 100% and 84% to 100% for the dysphonic speakers. Overall, the dysphonic speakers had a total mean of 10.93 errors and the healthy speakers had a total mean of 1.64 errors. A repeated measures ANOVA showed a significant difference between the number of errors, Wilks' $\Lambda = 0.220$, $F\,(1, 120) = 425.64$, $P \leq 0.001$. Observed power was 0.1.0 and the overall partial eta squared was 0.78 indicating that 78% of the variability associated with the number of speech intelligibility errors was attributed to voicing type.

All transcription errors were further reviewed to determine if listener transcription errors were related to content words (eg, listener transcribed "cat" for "dog") or article errors (eg, listener transcribed "the" for "a"). This division of words followed methods used in previous studies and ensured that the researchers were able to determine how much information listeners were actually missing from content words, rather than examining errors on articles which carry less meaning.[34,60] Articles were defined as the words "a," "an," and "the" and all other words constituted content words. Healthy speakers had a mean total of 0.69 errors on articles and 0.96 errors on content words. Dysphonic speakers had a mean total of 4.69 errors on articles and 6.24 errors on content words. Subsequent repeated measures ANOVAs showed significant differences between the mean number of article errors, Wilks' $\Lambda = 0.232$, $F\,(1, 120) = 396.45$, $P \leq 0.001$, and content errors, Wilks' $\Lambda = 0.388$, $F\,(1, 120) = 189.54$, $P \leq 0.001$, between the healthy and dysphonic speakers. Partial eta squared values indicate that 76% and 61% of the variability associated with the article and content errors, respectively, could be attributed to voicing type. In addition to significant differences in the number of errors between healthy speakers and those with dysphonia, listeners also had significantly more overall errors on content words than articles within voice type (healthy $P = 0.006$ and dysphonic $P \leq 0.001$).

2. *Effect of listener strategies*

In order to determine the effects of strategies provided to the listeners, a MANOVA was calculated using the total number of content and overall errors for the dysphonic speakers and the type of perceptual strategy provided (control, acknowledgment, perceptual strategy). Results of the MANOVA showed a nonsignificant main effect for

TABLE 1.
Descriptive Analysis of Overall Mean Data for Each Speaker

Voice Type	Age	Diagnosis	Total # Errors	Total # Content Errors	Mean # Errors (SD)	Intelligibility Range (%)	CAPE-V Rating					
							Overall Severity	Roughness	Breathiness	Strain	Pitch	Loudness
1	32	Healthy	45	4	0.4 (0.6)	96-100	3.93	3.53	0.75	3.80	1.54	0.07
1	26	Healthy	42	39	0.3 (0.6)	91-100	0.74	2.00	0.00	0.48	0.00	0.11
1	49	Healthy	94	60	0. 8 (1.0)	93-100	0.58	0.58	0.11	0.09	0.17	0.10
1	19	Healthy	18	13	0.2 (0.4)	96-100	3.34	3.00	0.56	0.69	2.17	0.46
2	42	Nodules	60	56	0.5 (0.8)	93-100	3.42	4.95	0.08	2.40	6.84	0.08
2	49	MTD	36	29	0.3 (0.6)	93-100	58.04	32.54	28.46	51.64	52.24	20.57
2	53	Polyp	60	60	0.5 (0.8)	93-100	42.91	45.81	25.90	38.55	16.56	33.18
2	32	Polyp, paresis	72	48	0.6 (1.0)	91-100	34.64	22.43	39.84	17.46	12.34	13.00
2	39	MTD	318	136	2.6 (1.5)	93-100	61.07	7.09	61.41	28.72	27.90	23.52
2	23	Nodules	176	65	1.5 (1.3)	93-100	46.15	22.58	40.31	32.54	13.17	14.73
2	20	Nodules	141	63	1.2 (1.1)	85-100	37.40	22.19	35.89	31.62	14.99	13.50
2	22	Nodules	63	24	0.5 (0.7)	95-100	22.13	17.61	13.06	16.69	14.13	3.65
2	30	MTD	108	32	0.9 (0.8)	89-100	50.20	47.97	5.70	22.23	40.36	4.48
2	50	MTD	48	26	0.4 (0.7)	93-100	2.24	3.10	0.41	1.14	5.95	0.30
2	19	Nodules	104	76	0.9 (1.1)	84-100	8.56	7.40	2.28	7.61	8.19	0.07
2	37	Nodules	212	140	1.8 (1.7)	95-100	31.72	34.36	10.95	14.63	22.66	2.88

Note. Voice type: 1 = healthy, 2 = dysphonic; SD = standard deviation; total # errors and total # content errors was calculated across all listeners; mean # of errors was calculated per listener; intelligibility range based on minimum and maximum number of errors across listeners divided by total number of words produced by each speaker; CAPE-V ratings are measured in mm (0-100) where a 0 = healthy and 100 = severe.

TABLE 2.
Number of Errors by Error Type and Strategy Across Listeners

	Strategy	Mean	SD
Total # dysphonia content errors	Control	7.07	5.31
	Acknowledgment	6.00	3.67
	Strategies	5.58	4.15
	Total	6.24	4.45
Total # dysphonia errors	Control	11.62	5.75
	Acknowledgment	10.61	4.57
	Strategies	10.50	5.69
	Total	10.93	5.34
Total # errors for both speaker groups	Control	13.24	6.23
	Acknowledgment	12.29	5.75
	Strategies	12.13	6.44
	Total	12.57	6.11

Note. SD = standard deviation; values calculated by dividing the total number of errors within each category by the total number of listeners.

effect of strategy for speech intelligibility, Wilks' $\Lambda = 0.969$, $F\ (4, 234) = 0.926$, $P = 0.449$. Observed power was 0.292 and the overall partial eta squared was 0.016 indicating that 1.6% of the variability associated with the number of speech intelligibility errors was attributed to strategy. However, descriptive analysis of the mean number of errors shows a trend of fewer errors when the listeners were provided with acknowledgement of the disorder or a perceptual strategy (see Table 2). Specifically, there were 15% fewer content errors in the acknowledgement group and 21% fewer content errors in dysphonic speech intelligibility when listeners were provided with strategies. Furthermore, there were 9% and 10% fewer total dysphonic errors when listeners were provided with an acknowledgment of the disorder or a perceptual strategy, respectively. Similar research on the impact of audiovisual information has found a ceiling effect where listeners do not benefit from the inclusion of visual information when a speaker is highly intelligible.[27]

To further elucidate the possible impact of either acknowledging the disorder or providing listeners with a perceptual strategy on the speech intelligibility of dysphonic speakers, two additional analysis of variance (ANOVA) were calculated. The first used the three dysphonic speakers whose intelligibility ranges fell below 90% and the second ANOVA used the three dysphonic speakers with the greatest number of overall errors. Results again showed that the presence of a strategy did not have a significant impact on the number of speech intelligibility errors ($P = 0.682$).

In order to determine if listeners were using any strategies other than those provided by the examiners, all listeners were asked the open-ended question at the conclusion of the listening experiment: "Did you find yourself using any strategies to figure out what the speakers were saying?" and "If yes, can you describe the strategies?" Responses that indicated listeners used other words or sounds were classified as "context clues." This category then encompasses both linguistic (using other words) and segmental (using other sounds within the word) strategies. Table 3 provides the number of listeners in each strategy group and the reported strategies used to help understand the speakers. Of note is the fact that no matter which strategies listeners were asked to use, the majority of listeners reported the use of "context" to better understand the speakers.

TABLE 3.
Total Frequency Count of Self-Reported Strategies Following Transcription Task

Control		Acknowledgment		Strategies	
Context clues	24	Context clues	27	Context clues	30
Repeat in head	4	Repeat in head	3	Segmental	5
Focusing	1	Focusing	3	Cognitive	3
Compared to other sentences	3	Compared to other sentences	3	Focusing	2
Repeat aloud	1	Prior experience	1	Segmental	5
Closed eyes	1				
Total	34	Total	37	Total	45

Note. The category *context clues* included responses indicating that listeners used other words/sounds to determine what they may have missed; those listeners who responded that they did not use any strategies ("none") were not included in the final total (control = 7, acknowledgment = 8, strategies = 14).

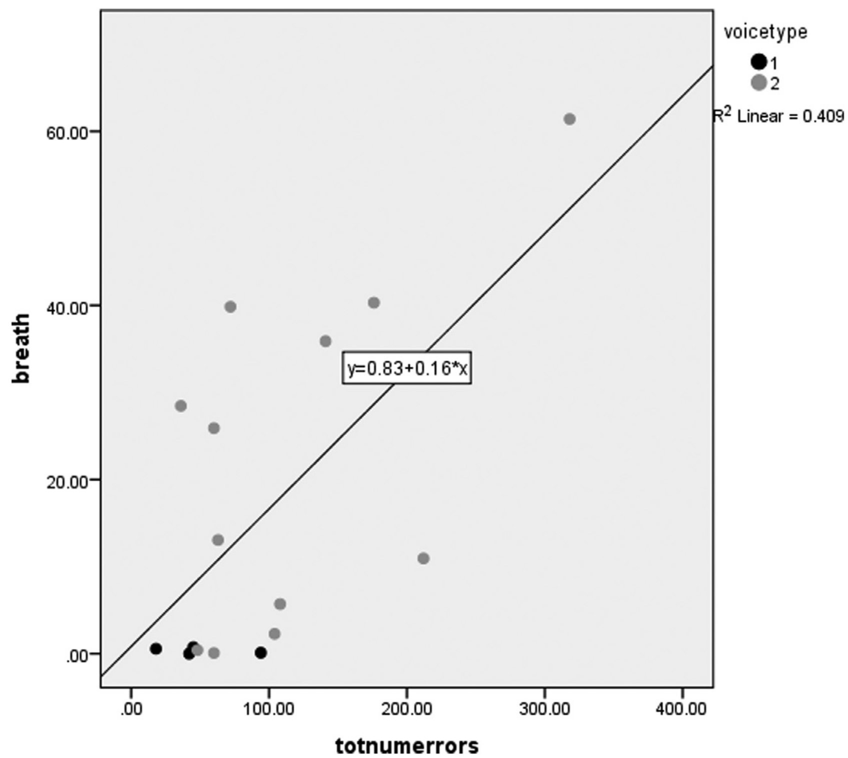

FIGURE 1. Line plot of regression analysis for breathiness rating and number of speech intelligibility errors. Note: voice type 1 = healthy, 2 = dysphonic.

3. *Voice quality ratings*

Finally, the third research question investigated whether expert, voice quality ratings obtained using the CAPE-V were predictive of the number of speech intelligibility errors. Table 1 shows the mean values across all three expert listeners for each voice quality category on the CAPE-V. Briefly, the mean overall severity rating for the healthy speakers was 2.15 mm while the mean overall rating for the dysphonic speakers was 33.21 mm. Although there were a large number of independent variables and thus a possibility of multicollinearity,[62] correlations among the variables were not calculated and a factor analysis was not completed due to the widespread clinical use of the CAPE-V and a desire to not collapse its ratings.

Using individual voice quality ratings from the CAPE-V (ie, overall severity, roughness, breathiness, strain, pitch, loudness), a regression analysis was calculated. Results showed one model that was predictive of the number of speech intelligibility errors. The model identified the voice quality breathiness which was able to predict 41% of the variance of intelligibility errors: $R^2 = 0.409$, $F(1, 15) = 9.71$, $P = 0.008$. Beta coefficient for the model was 0.64 indicating that for every unit increase (mm) in the voice quality rating of breathiness, there was a 0.64 increase in the number of errors. Visual inspection of the regression plot (Figure 1) suggests that speakers with a breathiness rating of moderate (20−50 mm) and severe (>50 mm) have a greater number of speech intelligibility errors.

DISCUSSION

The purpose of this study was to examine the impact of dysphonia on speech intelligibility and to investigate which, if any listener strategies might improve intelligibility scores with dysphonic speakers. Another purpose included determining the relationship between speech intelligibility and expert listener ratings using CAPE-V criteria. Results indicated that intelligibility scores were significantly higher for healthy speakers compared to those with dysphonia. Use of listener strategies was not found to improve speech intelligibility scores. Given the six rated categories on the CAPE-V, breathiness was shown to predict 41% of the variance of speech intelligibility errors. Implications of these findings will be discussed in more depth below.

Impact of dysphonia on speech intelligibility

Results of this study demonstrated a tenfold increase in the number of speech intelligibility errors for speakers with dysphonia compared to speakers with healthy voices. These findings support one recent study which indicated that dysphonic voices were significantly less intelligible compared to healthy voices.[34] Reduced intelligibility in speakers with dysphonia compared to healthy speakers has also been noted in the presence of background noise.[35,63] Previous studies have shown reduced intelligibility in speakers with dysarthria.[27−29] A common explanation involved deficits in articulatory skills as a main contributor to the reduction in intelligibility in speakers with dysarthria. Results of the current study lend credibility to the fact that part of the reduced intelligibility can be explained by voicing differences. Dysphonia often results from laryngeal pathology which affects the ability of the vocal folds to adduct and periodicity of vocal fold vibration.[64] These issues can result in noisy turbulence of air moving through the glottis and loss of harmonics, both of which can impact the ability of listeners to perceive contrasts between sounds.[65] This difficulty in distinguishing between sounds would have a clear impact on intelligibility scores. Currently, the impact of acoustic differences on speech intelligibility in dysphonic speakers is not well understood but studies from the past can be useful to focus on future directions. For example, investigation of vowel formants in dysphonic speakers revealed that noise and harmonic components of formants in vowels were impacted negatively.[66] This research demonstrated that certain vowels were impacted more than others and that the noise and lack of harmonic components increased as the severity of perceived dysphonia increased. This type of investigation leads to future research aimed at acoustic data as well as perceptual data to determine causes of reduced intelligibility in dysphonic speakers.

Results indicated that 78% of the variance associated with the intelligibility errors by listeners in the current study was found to be due to the presence or absence of dysphonia. Given that studies have indicated dysphonia in teachers leads to reduced student auditory comprehension in the classroom,[21,22] it is critical to further examine the negative impact that could be occurring during classroom learning. More investigation on both child and adult listeners with dysphonic speakers is justified, given that dysphonic speakers may be sending less intelligible messages in many professions. These might include speakers with dysphonia, such as university instructors[9–11] who may be less intelligible in classroom lectures and air traffic controllers who are relaying critical, urgent information to listeners.[14,15] Clinical application can also be taken from the findings that listeners may have difficulty understanding speakers with dysphonia. Clients with dysphonia should assess their communicative situations and make appropriate modifications when needed. For example, strategies to improve intelligibility or comprehensibility such as use of gestures and reducing background noise would be useful. Speakers with dysphonia may need to take special care to ensure that their listener understands their intended message.

In addition to presence or absence of dysphonia, it is important to consider other factors that may also have impacted intelligibility error scores. One factor that has been found in several studies is variability among listeners and evidenced in the current study by the range of intelligibility scores within speaker. The ability to correctly orthographically transcribe speech has been shown to vary among listeners, even when speech is produced by nondisordered speakers.[56,57] Significant variability among 228 listeners was found in a transcription task with dysarthric speakers.[67] Another study involving dysarthric speakers found that different listeners utilize different lexical boundary error patterns as cues to intelligibility.[68] Previously only one study has examined listener variability in speakers with dysphonia. Evitts and colleagues[34] also reported listener variability but errors related to the healthy speakers had relatively small variability and the variability of errors for the dysphonic speakers accounted for nearly 50% of the total mean scores. Overall, these studies lend support to the idea that there is definitely listener variability, and possibly an increase in variability in disordered versus nondisordered speech. It is possible that listener variability played a part in restricting the effectiveness of listener strategies in the current study. More research on the impact of listener variability on intelligibility tasks for speakers with dysphonia would add to overall understanding of factors that impact intelligibility in this population.

Effect of error types on intelligibility in dysphonia

A significant difference was found between content versus article error types within healthy and dysphonic speaker groups with more errors on content words compared to articles in both groups. This finding is similar to that of Hustad,[69] who examined intelligibility in speakers with dysarthria of differing severity levels. This study defined content words as nouns and verbs, modifiers as adjectives and adverbs, and functor words as prepositions, articles, and conjunctions. Findings indicated that listeners had greater transcription accuracy on noninformation bearing functor words, as opposed to the other word classes except in the most mildly impaired speakers. Turner and Tjaden[70] examined content versus functor word production of speakers with dysarthria secondary to Amyotrophic Lateral Sclerosis. Results indicated that differences in these words classes including shorter vowel duration and more centralization of the 1st and 2nd formant frequencies in functor words compared to content words. It is possible that these differences may add information or emphasis to the more important content words which may help listeners to focus the meaning of sentences.[71] These studies have conclusions based on speakers with dysarthria but it is possible the acoustic differences could exist in speakers with dysphonia as well. In addition, in English, articles also lend themselves to being somewhat interchangeable at times. For example, “A dog” versus “The dog” may not make much of a meaning difference in a transcription type setting. However, in a real-life conversation, this article change could alter the speaker’s meaning.

Impact of listener strategies on intelligibility in dysphonia

Use of listener strategies or acknowledgment was not found to increase the number of words correctly transcribed by listeners in the current study. Each listener in this study was asked about their use of strategy following the listening task and a majority of listeners reporting using “context” to understand words that were not intelligible. The impetus for examining the use of strategies which listeners were asked to use came from intelligibility literature using speakers with dysarthria. Klasner and Yorkston[47] examined four categories of listener strategies to investigate the impact on intelligibility with speakers with dysarthria secondary to Huntington's disease (HD) and amyotrophic lateral sclerosis (ALS). Their four categories of strategies included: segmental, suprasegmental, linguistic, and cognitive. Results revealed that cognitive and segmental strategies were commonly helpful to listeners with both HD and ALS-related dysarthria. Listeners primarily benefitted from segmental strategies in dealing with ALS speakers and from suprasegmental strategies with HD speakers. A more recent study[56] noted that cognitive and linguistic strategies were most highly endorsed by listeners dealing with dysarthria secondary to cerebral palsy.

The current study did not reveal that certain types of strategies were more helpful than others as previously noted with dysarthria speakers. The current study utilized three listener groups, including control, acknowledgement, and strategies. The strategies group were informed about the use of segmental, cognitive, and linguistic strategies as one entire strategy group. It is possible that if strategy types had been examined individually, a possible strategy effect may have been noted. Further the previous studies mentioned with dysarthric speakers utilized a research design where listeners were asked which strategies they endorsed, as opposed to the current study which assigned groups. On one hand, it is possible that strategies that are helpful for dysarthria simply do not benefit dysphonic speech. On the other hand, a starting place to examine this question likely lies in completing a study where listeners are asked about which strategies they endorse, as oppose to determining effects of preassigned strategies. Additionally, the speakers in the current study were found to be fairly intelligible with scores ranging from 84% to 100%. It is possible that due to a ceiling effect, there was little room for strategies to demonstrate improvement and further investigation of speakers with more severely impaired intelligibility is warranted.[27,56]

Relationship between voice quality ratings and intelligibility

Previous studies examining reduced intelligibility in dysarthria often include discussion of the articulatory impact. Given that the speakers in the current study did not have articulatory disorders and that the main difference between speaker groups was normal versus dysphonic speech, it is important to further discuss which voice quality descriptors might have more or less effect on what listeners perceive. In real-world listening situations, perceptual evaluation and description plays a major role in evaluation and treatment of speakers with voice disorders. The current study was constructed to include information to help identify which voice qualities may be at play during a reduction of intelligible speech by including CAPE-V ratings by expert listeners. There were significantly higher overall mean ratings for the speakers with dysphonia compared to the healthy speakers. Results indicated that one model, which represented breathiness was predictive of the number of speech intelligibility errors. A greater number of speech intelligibility errors were noted with speakers who received moderate and severe breathiness ratings. The variable of breathiness serving as the strongest predictor of intelligibility errors differs from the only other comparable study[34] where voice qualities that were predictive of speech intelligibility errors included overall severity and strain. It is possible that different etiologies and severity levels between the two studies was partly responsible for these differences.

Limitations

Generalization of results from this study to all speakers with dysphonia may be limited by several factors inherent to the study itself. First, a small sample size of speakers with dysphonia related to phonotrauma were included which does not allow to generalization of results to all speakers with dysphonia. Second, the speakers with dysphonia were relatively heterogeneous in severity. Other factors, such as differences in articulation, prosody, and voice quality may contribute to speech intelligibility and were not measured acoustically in this study but may have impacted intelligibility differences noted.[56] Future investigations should aim for a larger sample size of speakers with different types and severities of voice disorders. Second, listeners in this study had a mean age of 21.9 years and included more females than males. The ability to generalize findings to other age groups, populations, and/or languages of listeners is unknown. In order to more closely represent real-life communication situations, listeners of different ages and more closely balanced genders should be included in future studies. Third, generalization may be impacted due to the fact that the three expert listeners who provided the voice quality ratings were different than the listeners who performed the transcription task. While this can be viewed as a limitation to the study, it was by design in that the investigators were attempting to maintain realistic ecological validity. Given that a speaker with dysphonia would likely seek evaluation and treatment from a speech-language pathologist, it makes sense to have those individuals complete a task similar to what would be completed in that evaluation, such as the CAPE-V. However, in order to determine real-world intelligibility skills, every day or nonexpert listeners would also have stronger validity. Last, listeners completed the transcription task in a quiet environment that was the relatively free of any distractions. This situation does not simulate many real-life communication situations, and placed very few cognitive or attentional demands on the listeners. Future studies should increase the task demands placed on the listener during the actual transcription task. Many professional voice users with dysphonia work in environments with background noise so this could be a critical factor to consider in future studies. Including tasks such as following directions as opposed to intelligibility measures will have important implications for professional voice users, including teachers and air traffic controllers.

CONCLUSIONS

Results from this study provide further evidence that speakers with dysphonia have reduced speech intelligibility. Anecdotal reports indicated that listeners used context to determine words that were unintelligible during a transcription task but strategies were not found to improve intelligibility. Results from perceptual ratings indicated significantly higher overall rating scores equating to more severity for dysphonic speakers compared to healthy speakers and breathiness was found to be the most predictive factor in the variance of intelligibility errors.

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SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.jvoice.2019.03.013.

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