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Research Note

Speech Intelligibility in Speakers With Adductor Laryngeal Dystonia

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ABSTRACT

Purpose: Adductor laryngeal dystonia (AdLD) is a neurological voice disorder characterized by spasms in the adductory muscles of the larynx, resulting in a dysphonic voice with intermittent voice breaks. This study compared the intelligibility of individuals with AdLD to those without in noisy environments and characterized the relationship between their overall severity of dysphonia and intelligibility.
Method: Speakers (44 with AdLD and 44 age- and sex-matched controls) each read a unique set of stimuli from the Sentence Intelligibility Test. Overall severity of dysphonia was assessed by five experienced speech-language pathologists. Five inexperienced listeners orthographically transcribed all sentences presented with multispeaker babble. An analysis of variance was performed to determine the effect of group on intelligibility scores. The strength of the linear relationship between intelligibility and overall severity of dysphonia was assessed in the AdLD group.
Results: Individuals with AdLD had significantly lower intelligibility than controls. Individuals with AdLD with more severe dysphonia had significantly lower intelligibility.
Conclusions: AdLD negatively impacts an individual's ability to be understood in noisy environments, and this effect becomes stronger as dysphonia is perceived as more severe. These negative impacts on intelligibility should be considered when creating treatment strategies or counseling individuals with AdLD.

Laryngeal dystonia (LD), also known as spasmodic dysphonia, is a rare neurological voice disorder (Simonyan et al., 2021). Its proposed subtypes include adductor, abductor, and mixed, and tremor can co-occur within these subtypes (Blitzer et al., 1998; Simonyan et al., 2021). Adductor LD (AdLD) is the most common subtype, affecting from 82% (Blitzer et al., 1998) to 89% (Tisch et al., 2003) of patients with LD. AdLD is characterized by involuntary spasms in the muscles of the larynx that adduct the vocal folds during phonation (Aminoff et al., 1978). The involuntary spasms result in hyperadduction of the vocal folds, leading to intermittent voice breaks during voiced phonemes, pitch shifts, and auditory-perceptual features of strain and roughness (Blitzer, 2010; Roy et al., 2008; Simonyan et al., 2021). In contrast to behavioral voice disorders, voice therapy does not typically improve the primary symptoms for individuals with AdLD due to its neurological origin (Kodama et al., 2021).

LD may affect quality of life by restricting an individual's ability to participate in social situations due to challenges from the communication partner and the speaker (Baylor et al., 2005). Communication partners often make negative judgments about individuals with LD that extend beyond voice quality (Isetti et al., 2014). From the speaker's perspective, individuals with LD report feeling that their voice is unreliable, and experience moderate to extreme difficulties when speaking on the telephone and in noisy environments (Baylor et al., 2005; Smith et al., 1998; Yorkston

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et al., 2021). Being understood in noisy environments presents a significant challenge, as individuals have limited control over background noise in everyday situations. The inability to effectively adjust their speech to be successfully understood over noise can lead to frustration (Baylor et al., 2005). Understanding the specific struggles that individuals with LD face with communication partners is critical to understanding the psychosocial impacts of LD.

Although voice impairments are assessed primarily using measures that capture disruptions in the sound source, it is sometimes important to consider a metric of speech intelligibility, commonly defined as how well a speaker's message is understood by others (Yorkston, Strand, & Kennedy, 1996). Individuals with and without dysphonia exhibit high intelligibility when no background noise is present, consistent with the notion that most speakers with voice disorders (and who exhibit difficulties in the sound source alone) do not typically have reduced speech intelligibility in quiet (Ishikawa et al., 2017; Ma et al., 2021). However, as background noise increases relative to the speech signal, intelligibility decreases in both individuals with and without dysphonia, with a greater effect for the dysphonic speakers than the control speakers (Ishikawa et al., 2017; Ma et al., 2021). This effect of lower speech intelligibility in speakers with dysphonic voices than speakers with typical voices is consistently found, even in the absence of articulation impairments (Evitts et al., 2016; Ishikawa et al., 2021; Ma et al., 2021; Porcaro et al., 2020). However, many prior studies focused on other voice disorders that cause dysphonia (Evitts et al., 2016; Ishikawa et al., 2017, 2021; Ma et al., 2021; Porcaro et al., 2020), with few investigating these effects in LD (Bender et al., 2004; Finger et al., 2020; Patel et al., 2022).

Speech intelligibility in AdLD is important to understand because, beyond disruptions to voice quality and infrequent pitch shifts, individuals with AdLD may be uniquely differentiated from speakers with other voice disorders by intermittent voice breaks during voiced phonemes (Roy et al., 2008). These intermittent voice breaks result in communication partners receiving interruptions in the acoustic signal, which is vital for interpreting the message conveyed by speakers with AdLD. As a consequence, both the spectral and temporal content of the AdLD speech signal may be disrupted by abnormal voice quality as well as the flow of speech.

The limited studies of intelligibility in AdLD have assessed narrow ranges of overall severity of dysphonia (Bender et al., 2004) in small sample sizes (Bender et al., 2004; Finger et al., 2020; Patel et al., 2022), resulting in findings that may not be generalizable. Further, some studies that assess the intelligibility of dysphonic speech use vowel sounds or single words (Ishikawa et al., 2021; Lu & Matteson, 2014), which may not be as ecologically valid as sentence stimuli that are more linguistically complex than vowels or single words alone. A final important consideration in the assessment of speech intelligibility is the effect of background noise. Even in typical speakers, intelligibility is adversely affected by noise and thus intelligibility studies often use background noise to avoid ceiling effects of typical speakers (Ishikawa et al., 2017; Ma et al., 2021). However, there is also a growing body of evidence that in speakers with other types of voice disorders, intelligibility challenges may be compounded in noise, with the strongest impact on speakers with the most severe dysphonia (Ishikawa et al., 2017; Ma et al., 2021). Even though 80% of individuals with AdLD report having moderate to extreme difficulty being understood over background noise (Smith et al., 1998), its effects on speech intelligibility in AdLD remains poorly understood. Therefore, to gain a more holistic understanding of the impact that the intermittent voice breaks of AdLD have on intelligibility in everyday experiences, it is essential to assess intelligibility across a wide range of dysphonia severities using sentence-level speech presented with background noise.

The goal of this study was to assess how intelligibility differs between people with and without AdLD. To achieve this goal, we presented sentence-level speech in ecologically valid background noise (multispeaker babble). We hypothesized that intelligibility in noise would be lower in individuals with AdLD than in individuals without AdLD. We also assessed the relationship between overall severity of dysphonia and intelligibility, hypothesizing that more severe dysphonia would be associated with lower intelligibility in noise.

Method

All participants were fluent English speakers and provided informed consent in compliance with the Boston University (Protocol 2625), University of Texas Southwestern (Protocol STU 2023–0965), or University of Washington (Protocol STUDY00015518) institutional review boards.

Speech Samples

A total of 44 individuals diagnosed with AdLD (35 cisgender females, nine cisgender males, M = 61.9 years, SD = 12.1 years) and 44 controls[1] (35 females, nine males, M = 62.4 years, SD = 11.1 years) provided speech samples (see Table 1). Speakers in the AdLD group were otherwise absent of other speech, language, and hearing disorders, and were symptomatic at the time of assessment, which occurred within 2 weeks prior to their next scheduled botulinum toxin injection, except one individual who was not

[1]Gender information was not available for all participants.

receiving injections. Speakers in the control group were individually sex- and age-matched to speakers in the AdLD group within 4 years. Control speakers self-reported that they were absent of any speech, language, and hearing disorders.

Speech samples were recorded with a condenser microphone, placed 45 degrees from the midline and 7 cm from the lips, and were obtained at a 44.1-kHz sampling rate. Each speaker was instructed to read a unique set of Sentence Intelligibility Test (SIT) sentences (Yorkston, Beukelman, & Tice, 1996). Each speaker read six sentences, double the number needed for five listeners to accurately measure intelligibility (Dahl et al., 2024). The sentences were five, seven, nine, 11, 13, and 15 words long, resulting in a total of 528 sentence stimuli.[2]

Characterization of the Overall Severity of Dysphonia

The overall severity of dysphonia of the speakers were evaluated independently by five voice-specialized speech-language pathologists (SLPs) from the research team (four females, one male) using a custom MATLAB (MathWorks) graphical user interface with a visual analog scale (VAS). The VAS scale ranged from 0 to 100 with textual anchors placed at 10 for mild, 35 for moderate, and 72 for severe, consistent with the Consensus Auditory Perceptual Evaluation–Voice (Kempster et al., 2009). SLPs were blinded to the identity and diagnosis of the speakers and completed the ratings in a sound-attenuated booth during a single sitting that lasted an average of 1 hr. SIT sentence stimuli for each speaker were first concatenated into one sound file that was then peak-normalized and presented in a random order via Sennheiser HD 280 Pro headphones at a comfortable loudness that remained constant throughout the session. Each SLP rated the overall severity of dysphonia of 99 speech samples: 88 samples containing all SIT sentences from each speaker, followed by an additional ~12% (11 samples) that were randomly repeated at the end to assess intrarater reliability.

The SLPs had good-to-excellent intra- and interrater reliabilities as calculated via intraclass correlation coefficients (Koo & Li, 2016). The average ICC(2,1) for intrarater reliability was .95 (95% confidence interval [CI; .81, .99]) and the ICC(3,k) for interrater reliability was .98 (95% CI [.97, .98]).

[2]Although each set of sentences was generated specifically for individual participants, some repetition occurred due to larger sample sizes naturally increasing the likelihood of repetition. This resulted in a total of 367 unique sentences, accounting for 70% of the total sentence stimuli.

Auditory-Perceptual Experiment to Assess Intelligibility

Five inexperienced listeners (two cisgender females, three cisgender males; *M* = 22.6 years, *SD* = 4.2 years, range: 20–30 years of age) participated in an orthographic transcription task at Boston University; this number of inexperienced listeners previously has shown to be efficient and accurate for measuring intelligibility for this type of experiment (Dahl et al., 2024). All listeners had no history of any speech, language, and hearing disorders or any experience listening to atypical speech. To provide ecologically valid intelligibility ratings and avoid the potential bias toward higher scores associated with expert listeners (Finger et al., 2020; Patel et al., 2022), inexperienced listeners were recruited per the standard SIT protocol (Yorkston, Beukelman, & Tice, 1996). All listeners passed a hearing screening at 25 dB HL for the following frequencies: 250, 500, 1000, 2000, and 4000 Hz (protocol based on the Guidelines for Manual Pure-Tone Threshold Audiometry, American Speech-Language-Hearing Association, 2005).

Each listener was seated in a sound-attenuated booth for two sessions lasting 1–2 hr each, in which they listened to 592 speech samples (six SIT sentences per each of the 88 speakers, plus 12% of randomly repeated SIT sentences to assess reliability). All speech samples were randomized and peak-normalized using a custom MATLAB script, differing from the SIT protocol, where all stimuli from a single speaker are evaluated at once, and was implemented to minimize the influence of listener familiarity. To reduce ceiling effects and increase the ecological validity of speaking in everyday noisy environments, multispeaker babble was added to the stimuli. The babble was from eight individuals (four females, four males) with no speech impairments who were talking freely for 1 min or reading the rainbow passage. Each stimulus had periods of silence before and after the sentence, as in other intelligibility studies (Ishikawa et al., 2017; Ma et al., 2021), to allow the babble to surround the target sentence. To determine the signal-to-noise ratio (SNR), we conducted pilot testing of SNR levels ranging from −5 dB to +5 dB. The criterion was that the task would be challenging for the listener, regardless of whether the speaker had AdLD or not, resulting in an SNR of +1 dB.

The stimuli were presented via Sennheiser HD 280 Pro headphones at a comfortable loudness that remained constant throughout the session. Listeners could play each sample up to two times, as per the SIT protocol (Yorkston, 1984), and were instructed to transcribe the sentences they heard to the best of their ability without adding any punctuation. If they did not understand anything that was said, they were instructed to type only the letter “x.”

Intrarater reliability was calculated as the absolute value of the number of words correct in the first transcription,

Table 1. Demographics for speakers with adductor laryngeal dystonia (AdLD) and matched controls (CT), including mean overall severity of dysphonia rating (OS; 0–100) and mean intelligibility score (Intel; %).

AdLD group					Control group				
ID	Sex	Age	OS	Intel	ID	Sex	Age	OS	Intel
AdLD01	F	25	42.56	21.37	CT01	F	24	4.14	80.05
AdLD02	M	36	11.38	57.81	CT02	M	39	0.88	91.91
AdLD03	M	44	86.33	3.89	CT03	M	48	9.09	63.90
AdLD04	F	47	6.53	86.24	CT04	F	50	8.63	81.86
AdLD05	F	48	7.55	90.38	CT05	F	51	6.44	92.55
AdLD06	F	49	74.36	91.73	CT06	F	51	4.84	77.22
AdLD07	F	49	32.88	73.15	CT07	F	52	5.61	84.13
AdLD08	F	51	13.79	84.49	CT08	F	53	4.88	87.06
AdLD09	M	52	20.75	64.78	CT09	M	51	4.27	88.28
AdLD10	M	53	46.08	47.45	CT10	M	52	5.79	75.45
AdLD11	F	53	25.92	79.82	CT11	F	57	2.19	98.31
AdLD12	M	54	44.76	3.00	CT12	M	53	2.17	92.93
AdLD13	F	54	22.74	63.28	CT13	F	57	4.84	85.18
AdLD14	F	55	8.83	95.35	CT14	F	59	6.36	86.17
AdLD15	M	56	30.37	94.40	CT15	M	56	3.79	64.75
AdLD16	M	56	20.55	93.21	CT16	M	57	2.71	70.14
AdLD17	F	57	66.58	88.43	CT17	F	61	11.54	73.14
AdLD18	M	59	50.14	48.78	CT18	M	61	5.61	68.14
AdLD19	F	59	61.57	77.39	CT19	F	61	5.53	94.26
AdLD20	F	62	29.11	91.81	CT20	F	63	4.50	94.66
AdLD21	F	64	48.89	95.10	CT21	F	64	7.75	92.18
AdLD22	F	64	42.92	68.30	CT22	F	64	3.99	90.89
AdLD23	F	64	36.45	80.22	CT23	F	65	3.45	97.39
AdLD24	F	65	14.67	77.10	CT24	F	61	4.10	98.06
AdLD25	F	67	17.78	75.73	CT25	F	66	5.24	93.51
AdLD26	F	68	30.04	85.27	CT26	F	68	7.19	91.34
AdLD27	F	68	60.43	26.32	CT27	F	68	4.53	95.91
AdLD28	F	69	11.09	83.96	CT28	F	69	10.83	90.82
AdLD29	F	69	21.77	48.94	CT29	F	70	6.64	96.58
AdLD30	F	69	49.00	63.69	CT30	F	70	8.40	84.46
AdLD31	F	70	87.13	60.24	CT31	F	69	3.87	78.75
AdLD32	F	70	22.13	86.52	CT32	F	71	5.79	85.02
AdLD33	F	71	6.36	86.38	CT33	F	70	6.15	87.39
AdLD34	F	71	29.63	66.71	CT34	F	70	11.23	74.30
AdLD35	F	72	25.72	67.05	CT35	F	71	7.09	83.34
AdLD36	F	73	17.60	79.34	CT36	F	73	8.60	87.00
AdLD37	F	73	37.94	63.79	CT37	F	72	6.59	89.45
AdLD38	F	73	15.06	86.70	CT38	F	72	3.16	91.68
AdLD39	F	74	36.53	90.96	CT39	F	73	11.79	88.63
AdLD40	M	74	20.36	52.81	CT40	M	73	7.89	74.09
AdLD41	F	78	39.89	80.00	CT41	F	77	8.98	76.85
AdLD42	F	78	71.14	93.43	CT42	F	77	4.41	81.01
AdLD43	F	80	73.65	53.53	CT43	F	79	13.42	61.50
AdLD44	F	80	67.69	75.11	CT44	F	78	4.82	93.83

Note. ID = identification; F = female; M = male.

minus the number of words correct in the second transcription, averaged across the 12% repeated speech samples for each listener. Results revealed an average intrarater reliability of .79 words and standard deviation of .54 words. For interrater reliability, ICCs were calculated to compare the number of words correctly transcribed per sentence across listeners. The inexperienced listeners had good interrater reliability, with an ICC(3,k) of .95 (95% CI [.94, .95]).

Data Analysis

Intelligibility was measured as the percentage of words matching between the listener transcription and the true transcription of the sentences (Dahl et al., 2024). The first author used a custom MATLAB graphical user interface script to review each transcription, identify correctly transcribed words, and calculate the intelligibility score as the percentage of correct words relative to the total in the true transcription, following the scoring procedure outlined in Dahl et al. (2024). Words were counted as correct if they exactly matched the target, were a homophone, a contraction error (e.g., "we're" for "we are" and vice versa), a phonetically correct misspelling (e.g., "doon" for "dune"), spelling errors that did not result in another word (e.g., "wiht" for "with"), reversals in word order (e.g., "curly long hair" for "long curly hair," or number-word substitutions (e.g., "2" for "two"). Words were counted as incorrect if they had a typo that did result in another word (e.g., "bed" for "bead"), or were an error in plurality, tense, or possession. If the transcription had all words correct, but either inserted extra words (e.g., "never wanted" for "wanted") or had a partial contraction error (e.g., "they've" for "they"), all words were marked as correct and the denominator of the transcription was manually increased by one for each added word in the calculation of intelligibility score.

Statistical Analysis

To assess if intelligibility was lower for the AdLD group compared to the control group, we used a mixed-methods analysis of variance (ANOVA) to determine effects of group (AdLD or control), stimulus (sentence length), and their interactions on intelligibility. Speaker was included in the model as a random effect. To determine each speaker's overall intelligibility score, we averaged the intelligibility of all sentences per speaker, and then averaged each speaker's intelligibility score across all inexperienced listeners. To assess whether there was a relationship between overall severity of dysphonia and intelligibility for individuals with AdLD, we calculated a Pearson correlation between the average overall severity of dysphonia score for each AdLD speaker (averaged across the five experienced listeners) and the average overall intelligibility score for each AdLD speaker; results were interpreted per Cohen (1988). All statistical analyses were implemented using R software, with an a priori significance set to $p < .05$. Effect sizes for significant effects were calculated as partial eta squared (η_p^2) designated as small (~.01), medium (~.06), and large (~.14), as described in Cohen (1988).

Results

The mean overall severity of dysphonia rating was 36.0 (*SD* = 22.0, range: 6.0–87.0) for the AdLD group and 6.0 (*SD* = 2.0, range: 0–13.4) for the control group. Statistical results from the mixed-methods ANOVA are presented in Table 2. The mixed-methods ANOVA on intelligibility showed a large statistically significant effect of speaker group, with lower intelligibility in noise for the AdLD group (*M* = 70.5%, *SD* = 23.1%) relative to controls (*M* = 84.9%, *SD* = 9.8%). Figure 1 shows the differences in intelligibility scores for speakers with and without AdLD. There was a small, statistically significant effect of stimulus, with intelligibility decreasing as sentence length increased. There was no interaction between group and stimuli.

For those with AdLD, there was a moderately negative relationship between overall severity of dysphonia and intelligibility in noise ($r = -.35$, $p = .02$). Figure 2 shows that greater dysphonia severity was associated with lower speech intelligibility in noise.

Discussion

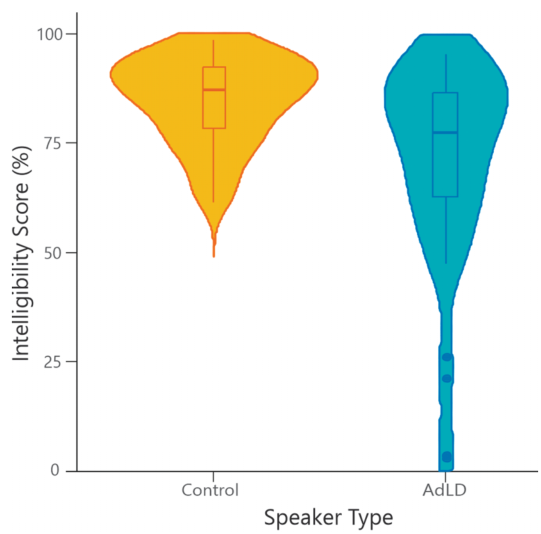
The current findings support the study hypotheses that intelligibility is, on average, significantly lower for individuals with AdLD than without in the presence of background noise, adding to prior literature showing speech intelligibility

Table 2. Results of the mixed-methods analysis of variance for intelligibility.

Effect	*df*	*F*	*p*	η_p^2	Effect size
Group	1	14.37	< .001*	0.14	Large
Stimulus	5	2.46	.033*	0.03	Small
Group × Stimulus	5	0.78	.568	NS	—

Note. NS = not significant; — = not applicable for nonsignificant findings.
*Significant at $p < .05$.

Figure 1. Mean intelligibility scores (percent correct words) for speakers with and without (control) adductor laryngeal dystonia (AdLD). Intelligibility for each group is represented by box plots and violin plots. For the box plots, each box expands from the first to third quartiles. The line inside each box represents the median, the whiskers represent the range, and any outliers are represented as individual points. For the violin plots, each violin represents the density of the speaker data points at each intelligibility score.



is disproportionally impacted in those with communication disorders (Ishikawa et al., 2021; Ma et al., 2021). In addition, individuals with more severe dysphonia demonstrated lower intelligibility in noise. Thus, AdLD impacts not only voice quality but also an individual's ability to be understood in background noise.

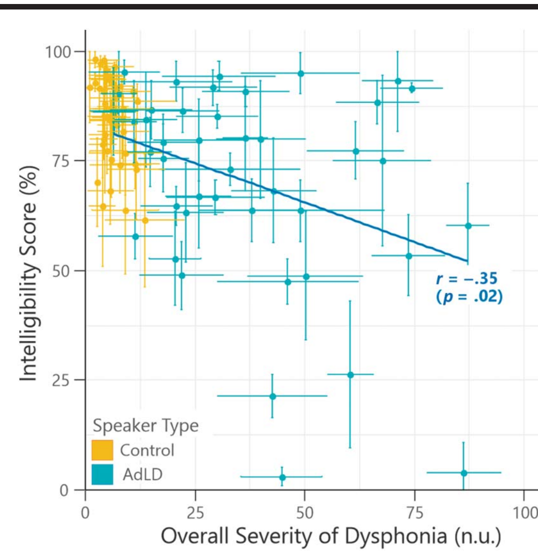
The current work found a significant moderately negative relationship between overall severity of dysphonia and intelligibility, showing that greater dysphonia severity is associated with lower intelligibility in noise in speakers with AdLD (see Figure 2). This finding is similar to Bender et al. (2004), who also found a moderately negative relationship ($r_s = -.35$) between clinicians' judgments of overall severity prior to botulinum toxin injections and intelligibility scores of 10 speakers with severe speech impairments due to AdLD. The strength of the relationship between dysphonia severity and intelligibility may be limited by other factors like phonatory break duration and pause time of the intermittent voice breaks unique to AdLD. Future studies should explore the possible basis of these relationships.

Stimulus length had a significant effect on intelligibility, with intelligibility decreasing as sentence length increased, and no interaction with speaker group. Although Ma et al. (2021) found that sentence length did not affect intelligibility in individuals with and without dysphonia due to phonotrauma, this discrepancy may be due to differences in speaker sample size, language (English vs. Cantonese), and clinical populations.

Findings from this study have potential to guide counseling and compensatory strategies in voice therapy for individuals with AdLD. Although voice therapy does not change the spasms that disrupt the speech signal (Kodama et al., 2021), it is possible that individuals with AdLD could employ other strategies to improve their communicative success. In the current study, a subgroup of speakers who had moderate-to-severe dysphonia (overall severity of dysphonia ratings between 61.6 and 74.4) also had high intelligibility scores in noise (intelligibility scores between 75.1% and 93.4%). Anecdotally, we noticed features that could have helped listeners distinguish the speaker's voice from the multispeaker babble, such as clear enunciation and consistent loudness, though consistent loudness may be an artifact of the peak normalization processing method. Future work may determine if these strategies could be employed to increase intelligibility of those with AdLD, in loud environments, while the effects of regular botulinum toxin injections are wearing off.

When interpreting and extending our results to everyday communication, it is important to consider that the speech recordings used in this study were collected in quiet with background noise added afterward; thus, we cannot account for any adaptive vocal responses that individuals with AdLD may exhibit in naturalistic noisy environments. In natural settings when speakers encounter background noise, they often make vocal adjustments in response, eliciting a Lombard effect (Lane & Tranel, 1971). There are conflicting findings on the impact that speaking in noisy environments has on individuals with AdLD, with some reporting

Figure 2. Mean intelligibility score (percent correct words) as a function of mean overall severity of dysphonia values per speaker with and without (control) adductor laryngeal dystonia (AdLD). Error bars are 95% confidence intervals.



that auditory-perceptual ratings and acoustic features of voice improve (Marchese et al., 2024), and others reporting decreases in intelligibility (McColl & McCaffrey, 2006). More research is needed on the effects of speaking in noise on AdLD as it is unclear from previous research.

There are several limitations to this study. The multi-speaker babble was implemented to create an ecologically valid environment, but this may have increased the distinction of the severely dysphonic speech from babble, comprising eight speakers without speech impairments. The unique auditory-perceptual characteristics caused by AdLD may have facilitated the listeners' ability to track the dysphonic speech. This study used unfamiliar listeners to assess intelligibility to reflect the impacts on intelligibility with new communication partners, but this does not reflect the speaker's intelligibility with more familiar listeners. We chose unfamiliar listeners to reflect real-world interactions, resulting in findings that are specific to intelligibility with unfamiliar communication partners. Finally, this study focused solely on the acoustic speech signal. To gain a more holistic understanding of how AdLD impacts intelligibility, future studies could qualitatively assess the speakers' experiences with intelligibility or consider the role of visual cues in communication. This would better inform our understating of the relationships among communicative participation, intelligibility, and dysphonia severity.

Conclusions

AdLD impacts an individual's ability to be understood by unfamiliar listeners in the setting of background noise. On average, the intelligibility of speakers with AdLD was significantly lower than that of speakers without AdLD, and worse intelligibility was associated with more severe dysphonia. The negative impacts of intelligibility should be considered when counseling and creating treatment strategies for individuals with AdLD.

Data Availability Statement

The data sets generated and/or analyzed during the current study are not publicly available due to commitments to protect participant confidentiality but are available from the corresponding author upon reasonable request.

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