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Tutorial

Obtaining Objective Clinical Measures During Telehealth Evaluations of Dysarthria

Jordanna S. Sevitz,[a] Brianna R. Kiefer,[b] Jessica E. Huber,[b] and Michelle S. Troche[a]

Purpose: COVID-19 has shifted models of health care delivery, requiring the rapid adoption of telehealth, despite limited evidence and few resources to guide speech-language pathologists. Management of dysarthria presents specific challenges in the telehealth modality. Evaluations of dysarthria typically rely heavily on perceptual judgments, which are difficult to obtain via telehealth given a variety of technological factors such as inconsistencies in mouth-to-microphone distance, changes to acoustic properties based on device settings, and possible interruptions in connection that may cause video freezing. These factors limit the validity, reliability, and clinicians' certainty of perceptual speech ratings via telehealth. Thus, objective measures to supplement the assessment of dysarthria are essential.
Method: This tutorial outlines how to obtain objective measures in real time and from recordings of motor speech evaluations to support traditional perceptual ratings in telehealth evaluations of dysarthria. Objective measures include pause patterns, utterance length, speech rate, diadochokinetic rates, and overall speech severity. We demonstrate, through clinical case vignettes, how these measures were completed following three clinical telehealth evaluations of dysarthria conducted via Zoom during the COVID-19 pandemic. This tutorial describes how each of these objective measures were utilized, in combination with subjective perceptual analysis, to determine deviant speech characteristics and their etiology, develop a patient-specific treatment plan, and track change over time.
Conclusion: Utilizing objective measures as an adjunct to perceptual ratings for telehealth dysarthria evaluations is feasible under real-world pandemic conditions and can be used to enhance the quality and utility of these evaluations.

The SARS-CoV-2 virus—commonly known as COVID-19—has altered the health care system by severely limiting the safety and access of all nonessential in-person health care and therapeutic services across the globe. In an effort to minimize viral spread and ensure the safety of patients and health care workers, telehealth has become a primary mode of service delivery across health care fields, including that of speech-language pathology. Over the last decade, telehealth had become an increasingly popular service delivery option; however, it had predominantly been utilized for patients in remote areas with limited access to care (Mashima & Doarn, 2008; Theodoros, 2008; Weidner & Lowman, 2020). The current pandemic has required clinicians who have had no prior experience with telehealth to use this service delivery modality with minimal best practice guidelines and evidence on how to evaluate and treat patients in a reliable and accurate manner.

Dysarthria accounts for a large portion of a speech-language pathologist's (SLP's) caseload, affects a wide range of patient populations, and can have a profound impact on communication effectiveness, social participation, and quality of life in affected individuals (Duffy, 2020; Dykstra et al., 2007). Dysarthria accounts for almost 50% of the neurological communication disorders that SLPs evaluate and treat (Duffy, 2020) and may be present in up to 90% of individuals with neurological impairments (Knuijt et al., 2014; Mitchell et al., 2020; Moya-Galé & Levy, 2019). Many adult patients with acquired dysarthria may be at an increased risk for developing severe consequences and mortality from COVID-19 due to advanced age, compromised respiratory systems, and the presence of comorbidities (Wu et al., 2020), further limiting the safety of in-person speech-language pathology services and increasing the demand for telehealth.

[a]Laboratory for the Study of Upper Airway Dysfunction, Department of Biobehavioral Sciences, Teachers College, Columbia University, New York, NY
[b]Department of Speech, Language, and Hearing Sciences, Purdue University, West Lafayette, IN
Correspondence to Michelle S. Troche: mst2139@tc. columbia.edu

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Additionally, the potential long-term effects of COVID-19 on the respiratory, laryngeal, and neurological systems may result in new or worsening dysarthria. A variety of neurological manifestations have been reported in patients with COVID-19, including acute cerebrovascular disease, stroke (Helms et al., 2020; Mao et al., 2020), and drug-induced toxicity (Spagnolo et al., 2020). Additionally, peripheral changes such as progressive pulmonary fibrosis may occur as a primary consequence of COVID-19. Also, essential acute care medical management, such as prolonged intubation and mechanical ventilation, may result in peripheral changes, including laryngeal injury, weakness, reduced sensation, and general deconditioning (Spagnolo et al., 2020; Zaga et al., 2020). Neurological consequences of COVID-19 may precipitate the development of dysarthria, and for patients with preexisting dysarthria, speech may worsen with additional neurological insult and/or peripheral changes.

Beyond COVID-19, many patients with neurogenic disorders suffer from movement disorders and other physical and cognitive limitations that serve as barriers to accessing clinics. It is likely that telehealth will become an increasingly popular mode of service delivery for individuals with dysarthria to improve access to care for those with physical and cognitive limitations, as well as for those who have difficulty accessing in-person service delivery due to geographic, time, and financial constraints.

Dysarthria results from a wide range of neurological etiologies that cause damage to the speech motor control system. Dysarthria can result from deficits to any or all of the five primary subsystems that are key to speech production: respiratory, laryngeal, velopharyngeal, orofacial, and prosodic. An accurate evaluation of dysarthria includes both an objective and subjective analysis of the speech subsystems, as well as their interactions with one another (Yorkston et al., 1999). Objective measures can be derived from a number of different sources and may be helpful in quantifying, confirming, and refining perceptual findings, as well as providing insight into the pathophysiology of the motor speech disorder (Duffy, 2020). However, obtaining objective measures of speech production can be a challenge in clinical practice due to time constraints and limited access to equipment. Consequently, according to Duffy (2020), SLPs often use subjective ratings as the primary and/or sole method for the evaluation and diagnosis of dysarthria. However, perceptual ratings are highly subjective and often unreliable within and across raters (Bele, 2005; Halberstam, 2004; Kearns & Simmons, 1988; Revis et al., 1999). For the aforementioned reasons, objective measures of speech production should be used as an adjunct to subjective ratings in all settings. When used appropriately in combination, perceptual and objective measures allow for the correct identification of speech features that most severely affect naturalness and intelligibility, dysarthria type and severity, and therapeutic targets. They also enable clinicians to track change over time.

There is limited research on the efficacy and reliability of telehealth evaluations of dysarthria (Weidner & Lowman, 2020). When comparing perceptual evaluations in the face-to-face and telehealth modalities, a few studies have identified measures such as dysarthria severity, intelligibility at the sentence and conversation level, and articulatory precision to be reliable between modalities, as well as within and between raters (Constantinescu et al., 2010; Hill et al., 2006, 2009). However, in these same studies, perceptual ratings of voice such as vocal loudness and vocal quality made from telehealth evaluations exhibited poor agreement with perceptual ratings of voice from face-to-face evaluations (Constantinescu et al., 2010; Hill et al., 2006, 2009). Importantly, these studies have all been conducted under ideal circumstances with specialized equipment, including custom-built video conferencing software, external web cameras set at a specific angle and focus, a headset microphone worn by participants, and participants positioned at a set distance from the microphone and monitor (Constantinescu et al., 2010; Hill et al., 2006, 2009). While this equipment allows for enhanced measurement precision, providing this equipment to all patients may not be feasible for the majority of clinicians due to constraints of finances, time, and resources, especially during the COVID-19 pandemic. Additionally, perceptual analysis of dysarthria via telehealth is further limited by the automatic speech compression algorithms and sampling rates that are inherent to most telecommunication platforms. These may alter speech parameters and impact intelligibility, making it difficult to distinguish dysarthric patterns from transmission artifacts in individuals with dysarthria (Utianski et al., 2019).

Given the limited translation of the existing research to the current clinical context and the limitations of the perceptual analysis of dysarthria in the telemodality, the question remains: How can SLPs provide reliable telehealth evaluations to patients with dysarthria? In this tutorial, we describe objective measures that can be easily obtained in real time and from recordings of speech telehealth evaluations conducted via popular web-based interfaces and how these can be used as an adjunct to subjective ratings to enhance the quality and utility of telehealth dysarthria evaluations. We then provide three clinical vignettes based on our telehealth evaluations during the COVID-19 pandemic to highlight how these measures can be used to enhance clinical practice.

Tutorial on How to Obtain Objective Measures From a Motor Speech Evaluation via Telehealth

There are a number of objective measures that can be derived from motor speech evaluations conducted via telehealth. These objective measures can be derived in real time and/or from acoustic recordings. Below, we outline step-by-step procedures for obtaining such measures from telehealth evaluations, with the goal of providing a means to objectively identify speech deficits, identify appropriate treatment targets, and track progress over the course of therapy. It is important to note that, while objective measures have the potential to be more reliable than subjective perceptual measures, they too can suffer from interpretation or measurement error in the absence of clear operational definitions. Training is necessary to ensure consistency between evaluators and across time.

Obtaining valid clinical outcomes starts with a rigorous and repeatable evaluation protocol and measurement approach. A standardized protocol for assessment and clinical outcome measurement should be used between patients and across visits in order to ensure that differences in clinical outcomes can be attributed to disease or treatment effects and not variability in the assessment or measurement protocol. An example of a standardized perceptual speech evaluation, which examines the individual speech subsystems, speech during reading, and speech in conversation, is included in Appendix A. A perceptual rating form, which can be used as a guide to rate the presence and severity of deviant speech characteristics in each subsystem, can be found in Duffy (2020, Box 3-2).

To our knowledge, there are currently no data supporting the reliability and validity of perceptual speech ratings of telehealth evaluations conducted under current real-world clinical conditions. Given the current lack of data and the inherent challenges in making perceptual speech ratings from telehealth evaluations, the addition of objective measures into clinical telehealth dysarthria evaluations provides a comprehensive approach to motor speech assessments that can be more easily standardized and measured in a reliable manner.

Obtaining Objective Speech Measures During a Telehealth Evaluation

Acoustic analyses of all tasks from a motor speech evaluation are time consuming and may not be feasible in most clinical settings. Below, we provide instructions on how to easily obtain objective measures of speech production in real time during a telehealth dysarthria evaluation. The real-time measures described here will add only a few minutes to assessment time, and the measures from recordings can be completed quite quickly, depending on the number of stimuli measured. Consistency is critical when selecting the tasks for measurements. For example, if time permits, we recommend analyzing the entire first paragraph of "The Rainbow Passage" (Fairbank, 1960; see Appendix C) and a standard conversational sample for the most representative results. However, in the presence of time constraints, you may consider obtaining the acoustic measures described from two to three sentences of "The Rainbow Passage" (e.g., "The rainbow is a division of white light into many beautiful colors. These take the shape of a long round arch with its path high above and its two ends apparently beyond the horizon."). It is important to analyze the same tasks and sentences between patients and across sessions for purposes of comparison and in order to measure the impact of disease and treatment on speech production.

Breath Pause Patterns

Pauses in speech serve two important roles: (a) to provide the speaker with an opportunity for gas exchange/breath support and (b) to parse speech into syntactically meaningful units. The number and location of breath pauses relative to syntax can provide important information regarding the patient's respiratory drive and coordination as well as motor planning used for speech production (Darling-White & Huber, 2020; Huber et al., 2012). Inappropriate silences/pauses are a common perceptual characteristic in individuals with dysarthria (Darley et al., 1969). Irregular pause patterns can lead to reduced naturalness and may reduce comprehensibility by making it difficult for the listener to parse running speech into meaningful units (Price et al., 1991; Shah et al., 2006). Breath pause patterns can be measured during reading of "The Rainbow Passage."

In the analyses we present in the cases below, breath pauses are defined by locations where the patient inspires. Additional nonbreath pauses associated with linguistic factors (e.g., pauses for emphasis) or movements related to dyskinesias or disfluencies were not counted as pauses for this analysis. In Appendix C, we provide a template for "The Rainbow Passage" that includes syntactic classifications of potential pause locations—marked by a linguist from Purdue University, Elaine J. Francis. Two pause boundary classifications are specified: major and minor. Major boundaries are those that occur after an independent clause; minor boundaries are those that occur after a subordinate clause or phrase; all other boundaries are deemed as boundaries unrelated to syntax (e.g., in the middle of a phrase or between a single word pronoun and verb phrase). While measuring each pause, make note of where the pause falls in relation to these specified boundaries. If a pause falls at a location that the template indicates as a "major" or "minor" boundary, then it is considered syntactically appropriate. Pauses that fall at locations that are not indicated in the template are not syntactically appropriate. To determine where/when pauses occur in real time, observe the patient's shoulders and chest. They will rise when the patient inspires. Keep in mind that the movements of the chest and shoulders may be small in some patients, and both the chest and shoulders may not move to the same extent across breaths and even shallow movement may represent a breath. Visualizing the abdomen may also facilitate identification of a breath; however, depending on the camera angle and view, this may often not be feasible via telehealth. Looking at the patient's face and mouth may provide additional insight into whether or not a breath was taken. It is also important to remember that inspiration may or may not be audible. Make a mark indicating where each breath occurs on a printed copy of "The Rainbow Passage" that contains the syntactic boundary markings (see Appendix C). Be sure to only mark pauses where an inspiration occurs. The markings can be made during the reading task. Following the evaluation, you can use these markings to count the total number of inspiratory pauses and determine the percentage of pauses produced at major syntactic boundaries, minor syntactic boundaries, and unrelated syntactic boundaries. Normative data for young adults and older adults are provided in Huber et al. (2012) and Darling-White and Huber (2020).

Utterance Length

Utterance length provides valuable insight into the patient's respiratory support for speech production as longer utterances reflect greater respiratory support (Huber & Darling, 2011; Huber & Darling-White, 2017). Utterance length can be derived from "The Rainbow Passage" by counting the number of syllables the patient produces per utterance. An utterance may be considered the segment of speech that falls between two breath pauses. If a patient has poor respiratory support, they will need to inspire more often, resulting in shorter utterances. To calculate the patient's average utterance length, divide the total number of utterances produced by the total number of syllables produced during reading. There are 127 syllables in the first paragraph of "The Rainbow Passage." The number of utterances produced will be one more than the number of pauses (e.g., if you identify 12 pauses, 13 utterances were produced). Patients may add words or not produce all words in a passage. Try to note those changes on your printed copy of the passage as you are listening to the patient read the passage. Following the evaluation, you can add/subtract them from the total number of syllables to compute utterance length. Normative data for utterance length for young and older adults can be found in Hoit et al. (1989), Hoit and Hixon (1987), Huber and Darling-White (2017), and Huber (2008).

Speech Rate

Speech rate frequently becomes reduced with many disease processes, although it may also become increased in some disorders such as in Parkinson's disease (PD; Duffy, 2020). Both fast and slow rates of speech have a significant impact on naturalness and intelligibility. Speech rate can be measured during reading of "The Rainbow Passage" (see Appendix C) and/or from a spontaneous speech sample. Speech rate may vary with linguistic load, and therefore, measuring speech rate using two distinct tasks (e.g., a reading task and a conversational task) may provide valuable information. Typically, speech rate will be slower in conversation than in a reading task (Huber & Darling, 2011). It is important to note that calculating speech rate from a spontaneous speech sample would require orthographic transcription and subsequent counting of words after the evaluation session is complete. To calculate speech rate during reading, you may use a stopwatch or a phone app to measure the time it takes the patient to read the passage, including pause time. The number of syllables in "The Rainbow Passage" is 127. As with utterance length, make note of word changes, additions, or fillers such as "um" to add or subtract them from your total syllable count. This can be easily done by noting changes on a printed copy of "The Rainbow Passage" (see Appendix C). To calculate speech rate, divide the number of syllables by the time taken to read the passage. The same methodology can be used with a spontaneous speech sample once the sample has been orthographically transcribed. Normative data for young and older adults can be found in Huber (2007), Huber and Darling (2011), and Huber and Darling-White (2017).

Diadochokinetic Rates

Diadochokinetic (DDK) rates are frequently used to inform differential motor speech diagnosis and make determinations about severity and intelligibility (Pierce et al., 2013). While their primary purpose is to assess speed and regularity of speech movements, they also provide information about articulatory precision, velopharyngeal closure, and respiratory and phonatory support for sustaining speech (Duffy, 2020). DDK rates can be objectively measured during an evaluation using a stopwatch or a phone app with a lap function. Instruct your patient to "Take a breath and repeat /pʌpʌpʌpʌpʌ/ for as long and steadily as you can." A 3- to 5-s sample is sufficient to make clinical judgments (Duffy, 2020). This should be repeated with the following sounds: /pʌ/, /tʌ/, /kʌ/, and /pʌtʌkʌ/—each one preceded by a 2- to 3-s clinician model (Duffy, 2020). Press "start" on your stopwatch when the patient begins and press the "lap" button for each syllable repetition. Number of syllables per second is computed by dividing the total number of syllables by the duration of the task (in seconds). It is important to note that this measure may be difficult to obtain in real time for some individuals with rate disturbance, particularly those with exceptionally fast or irregular rate and imprecise articulation. In these cases, objective analysis after the evaluation may be necessary to calculate DDK rate. Normative data for DDK rates can be found in Kent et al. (1987) and Pierce et al. (2013).

Overall Speech Severity

Overall speech severity is a useful way to characterize the extent of a patient's dysarthria and, according to Duffy (2020), should always be estimated in order to (a) establish a baseline at initial evaluation, which can be used as a comparison at subsequent evaluations; (b) facilitate appropriate decisions and recommendations regarding prognosis and management; and (c) serve as a comparison to the patient's complaints—gross mismatches between clinician and patient perceptions may lead to further considerations (Duffy, 2020). Measuring severity may be particularly helpful in conveying the impact of mild–moderate speech impairments, where deficits may not be captured by a percent intelligibility score, despite the fact that naturalness and communicative effectiveness are significantly impaired (Sussman & Tjaden, 2012). Using a visual analog scale (VAS) has been shown to be a reliable method of measuring voice changes (Martins et al., 2015). A VAS may be an effective method of capturing the extent of speech changes across the widest range of dysarthria severities and has been shown to differentiate healthy older adults from those with neurological diagnoses, such as multiple sclerosis and PD, and to be sensitive to differences in speech severity within an individual (Sussman & Tjaden, 2012). While we are not aware of any studies that have used a VAS to track change pre- to posttreatment, the published data suggest that VAS would be effective to measure change as a result of treatment. Speech severity can be measured using a VAS such as the one in Appendix B. At the conclusion of your evaluation, consider the patient's speech severity across all assessment tasks and make a mark on the line to indicate the severity of speech disorder you perceive. Percent severity is computed by dividing the length from the normal end of the scale to the mark you made by the total length of the line.

Obtaining Objective Measures From Analyses of Acoustic Recordings

If time permits, conducting an in-depth acoustic analysis of recordings from the motor speech evaluation via Praat (Boersma & Weenink, 2008), a free acoustic analysis software available for download, can be of value as it provides more precise measurement. Praat can be downloaded for Windows (https://www.fon.hum.uva.nl/praat/download_win.html) and for Mac (https://www.fon.hum.uva.nl/praat/download_mac.html). Below, we outline instructions for how to obtain objective measures from acoustic recordings of telehealth motor speech evaluations via Praat.

The telehealth service delivery model poses several challenges that limit the acoustic analyses, which can be validly completed from recordings of evaluations via standard videoconferencing software (Theodoros & Ramig, 2011). Telehealth therapeutic studies that have included acoustic outcome measures, such as sound pressure level, have utilized customized systems with calibrated acoustic software (e.g., Theodoros et al., 2016). For the majority of clinicians without access to such equipment, two challenges to measuring sound pressure level are the inability to calibrate the microphone for sound pressure level and the difficulty of reliably controlling mouth-to-microphone distance and angle. Some common acoustic measures are impacted by built-in settings for most telehealth platforms that automatically adjust the spectral qualities of acoustic recordings in the presence of background noise or low microphone volume, for example. Because of this, common acoustic measures of loudness, such as sound pressure level, or vocal quality, such as cepstral peak prominence, cannot be reliably obtained from telehealth evaluations in the absence of customized equipment or software in real time or after the fact. However, frequency measures can be derived from acoustic recordings, as described below.

Recording Acoustic Speech Samples via Telehealth

Acoustic recordings may be obtained from evaluations conducted via any telehealth platform. For example, one popular platform (Zoom; Zoom Video Communications, Inc., 2016) contains a "record" feature within the application, and once the meeting has ended, Zoom produces a video and audio file of the session. Before making any recordings of telehealth evaluations, we recommend consulting with the clinical facilities' information technology and/or data safety office to ensure session recordings are stored in a safe and secure, HIPAA-compliant manner.

Converting the Acoustic Recording for the Analyses

To be compatible with Praat, an acoustic analysis software, the audio file produced will need to be converted to a WAV or MP3 file prior to the analysis. If using a Mac, the file can be converted from an MP4 to an MP3 in iTunes. For Windows, the conversion can be done through GoldWave (GoldWave, Inc., 2009), a free digital audio editor software available for download from the Internet. GoldWave can be downloaded here: https://www.goldwave.com/release.php.

1. Open the MP4 audio recording file in iTunes.
2. Once it is selected, click "file" and then click "convert."
3. Select "create MP3 version." An MP3 version of the file with the same name will then appear in iTunes.

1. With GoldWave open, exit out of the GoldWave Help window.
2. Click "File" then "Batch Processing."
3. Under the "Source" tab in the "Batch Processing" window, click "Add files" and then select the MP4 file from the known location on your computer. Click "Add."
4. Click the "Convert" tab from the "Batch Processing" window. Check the box that indicates "Convert files to this format." From the "File type" dropdown selection, select Wave (.wav) or MP3 (.mp3). Make sure the "Filters" dropdown selections are as follows: "All channels," "All rates," and "All bitrates." Then, select PCM signed 16 bit, stereo.
5. Click the "Destination" tab from the "Batch Processing" window to indicate where you want the new file type to be saved on your computer. Select the bullet point to "Store all files in this folder," click the folder icon on the right-hand side, and select the location of choice.
6. Click "Begin" from the bottom of the "Batch Processing" window.
7. Once the file conversion has been completed, a green checkmark icon will appear in the "Processing Messages" window. Select OK and exit out of GoldWave.

Opening the File in Praat

Complete the following steps to open the converted file in Praat and begin the analyses:

1. Once Praat is open, exit out of the "Praat Picture" window.
2. In the "Praat Objects" window, click "Open," then "Read from file."
3. Select the WAV or MP3 file you wish to open. It will be in the location you saved it in during the GoldWave/iTunes conversion. Click "Open."
4. Your file will appear in the "Praat Objects" window. Highlight the file and then click "View and Edit."
5. The acoustic waveform and spectrogram of the recording will appear. The acoustic waveform is an amplitude by time representation of your recording. The spectrogram is more complex—the frequency

is represented on the *y*-axis, time is represented on the *x*-axis, and amplitude is represented by the darkness of the signal.

6. To zoom in/out on the file, use your cursor to highlight a portion of the recording you wish to analyze and select the “sel,” “in,” or “out” buttons. The “in” and “out” buttons zoom in and out of the working location in the file, respectively, while the “sel” button zooms into a highlighted section of the recording.
7. Use the sliding bar at the bottom of the window to move to different locations in the file.
8. To play the audio, use your cursor to highlight the portion of speech that you wish to listen to and click the gray bar directly below the highlighted section of the spectrogram.

Acoustic measures of fundamental frequency (F0) range and variability can only be obtained from a recording (not in real time). These measures provide objective data to describe a patient’s prosodic contour and to support perceptual ratings of monopitch or monoloudness (Duffy, 2020). Pitch abnormalities are common in people with dysarthria (Darley et al., 1969) and have been shown to contribute to word- and sentence-level intelligibility (Duffy, 2020).

Using your cursor to highlight the section of speech you want to measure, follow these steps to complete each desired outcome measure in Praat. These measures can be made on a pitch glide, individual utterances, or connected speech. Normative data for a variety of F0 measures may be found in studies of Banh et al. (2009), Berg et al. (2017), Boone et al. (2005), Goy et al. (2013), and Reich et al. (1990). After selecting the portion of the sample, you want to analyze, you can use the following menus to obtain F0 data.

1. Mean F0: Click “Pitch,” then “Get pitch” to obtain the mean F0.
2. F0 Minimum: Click “Pitch,” then “Get minimum pitch.”
3. F0 Maximum: Click “Pitch,” then “Get maximum pitch.”
4. F0 Variability: Click “File,” then “Extract selected sound (time from 0).” In the Praat Objects window, highlight “Sound untitled,” then click “Analyze periodicity,” “To pitch,” then “OK.” Highlight “Pitch untitled” in the Praat Objects window, click “Query,” then “Get standard deviation.”

Clinical Case Vignettes

The following clinical case vignettes are based on patients evaluated as part of an institutional review board–approved clinical research initiative to assess the speech and swallowing of patients with movement disorders via a telehealth service delivery model (Zoom) during the COVID-19 pandemic. Patients provided consent prior to participation. All patients used a device of their choosing (i.e., cellphone, tablet, laptop, desktop), with audio and video capability. Participants were not provided any additional equipment or equipment specifications. Participants were instructed to sit upright comfortably in a chair, in a room with no background noise, and angle their camera such that their entire face and upper torso were visible in the screen. Patient distance from their device and/or microphone was not standardized or calibrated. Patients were instructed to sit with their arms down by their sides, not on surfaces/chair arms, for the purposes of easily identifying breath pauses. Caregivers were encouraged to remain present for the evaluation, but this was not required. Assessment tasks are provided in Appendix A. Participant consent to audio- and video-record was obtained, and the evaluations were audio- and video-recorded via Zoom and saved to a secure server. All objective and subjective measures were completed after the evaluation from the video and acoustic recordings obtained via Zoom. Objective measures were compared to normative data for healthy older male adults in the cases below. We considered measurements within 1 *SD* from the mean as within normal limits. Through the following case vignettes, we will highlight the feasibility of obtaining and utilizing objective and subjective speech production outcomes via telehealth for the management of motor speech disorders.

Case 1: 8-Year History of PD

Perceptual Evaluation

Perceptual evaluation revealed a moderate hypokinetic dysarthria. The patient’s speech naturalness and intelligibility were primarily impacted by a moderately rough vocal quality and mildly reduced loudness. However, these ratings may not be reliable given the reported difficulty with perceiving these characteristics over telehealth platforms (Theodoros & Ramig, 2011). It is particularly difficult to perceptually assess loudness via telehealth due to inconsistencies in microphone-to-mouth distance, lack of calibration, automatic changes in gain and acoustic properties of telehealth recordings, and possible changes in signal and connection that may cause momentary video/audio freezing. Given the prevalence of reduced loudness in many populations and its centrality in reducing speech intelligibility, additional measures that provide information about the respiratory system, such as utterance length and pausing patterns, may be particularly helpful when engaging via telehealth for diagnosis and treatment planning. This patient’s motor speech production was also characterized by mildly reduced articulatory precision and mildly reduced prosodic contour (see Table 1).

Objective Evaluation

Objective evaluation revealed frequent pausing at unrelated syntactic boundaries (47.4%) and very low frequency of pauses at major syntactic boundaries (18.8%). Pausing at unrelated syntactic boundaries has been identified as a common finding in PD due to reduced respiratory coordination and flexibility for speech (Darling-White & Huber, 2020).

Table 1. Case 1: Objective and perceptual measures of motor speech obtained from telehealth evaluation.

Measure	Patient	Norms, *M* (*SD*)
Objective measures		
Speech rate	3.37 syllables/s[a]	4.6 (0.18) syllables/s
Utterance length	8.12 syllables[a]	13.2 (1.01) syllables
No. of pauses	12	13.4 (2.45)
% of pauses at major boundaries	18.8%[a]	67.2% (7.8)
% of pauses at minor boundaries	37.5%	32.1% (6.4)
% of pauses at unrelated boundaries	43.8%[b]	0.8% (1.7)
DDK rates	/pʌ/ = 7.2[b]	/pʌ/ = 6.3 (0.7)
	/tʌ/ = 6.8	/tʌ/ = 6.2 (0.8)
	/kʌ/ = 6.8[b]	/kʌ/ = 5.8 (0.7)
	/pʌtʌkʌ/ = 6.0[b]	/pʌtʌkʌ/ = 5.0 (0.7)
Mean F0	100 Hz	126.7 (27) Hz
F0 minimum	83 Hz	82.6 (11) Hz
F0 maximum	413 Hz	363 (103) Hz
F0 variation	7 Hz[a]	> 25 (8) Hz
Perceptual measures		
Vocal quality	Rough	
Loudness	Inadequate	
Pitch range	Inadequate	
Rate	Speed: normal	
	Pace: consistent	
Articulatory precision	Precise	
Resonance	Hypernasal	
Prosody	Intonation: monotonous	
	Stress reduced	
Fluency	Neurogenic stuttering: no	
	Palilalia: no	
% Overall severity	47.2%	
Dysarthria type	Hypokinetic	

Note. DDK = diadochokinetic; F0 = fundamental frequency.

[a]Below normal range. [b]Above normal range.

A slow rate of speech (3.37 syllables/s) and reduced utterance length (8.12 syllables) were also identified. However, in this case, slow rate and reduced utterance length did not appear to be perceptually impacting intelligibility, naturalness, or communicative effectiveness and were not areas of primary concern for the patient. Minimum pitch and maximum pitch were within normal limits; however, pitch variation was significantly reduced, supporting the perceptual finding of monotonous prosody.

Putting It Together

Given the uncertainty of subjective perceptions of loudness and vocal quality via telehealth, the objective data bolster the subjective findings and help to explain the potential etiology of the perceptual characteristics. The objective finding of increased pausing at inappropriate syntactic boundaries, reduced pausing at major boundaries, and reduced utterance length suggest that the perceived rough vocal quality and reduced loudness may be due, at least in part, to deficits in respiratory control. This builds a rationale for a treatment approach focused on improving respiratory coordination and support for speech in order to improve vocal quality and loudness. Although deficits in other subsystems were identified, given that vocal quality and loudness appeared to be impacting speech naturalness and intelligibility the most, a treatment approach targeting these deviant speech characteristics is appropriate. It is important to note that we cannot rule out contributions from the laryngeal system without instrumental assessment of laryngeal structure and function.

Use of subjective ratings of the severity of vocal quality and loudness to track change secondary to treatment is limited given that these ratings cannot be reliably completed via telehealth without specialized equipment and software (Theodoros & Ramig, 2011). Instead, the quantitative measures of pause location and frequency can be used to more precisely monitor improvement over the course of therapy.

Case 2: 11-Year History of PD

Perceptual Evaluation

Perceptual evaluation revealed a severe hypokinetic dysarthria. The clinician perceived moderately reduced loudness, severe breathy vocal quality with periods of aphonia, and a slow rate of speech during conversation. Mild hypernasality, monotonous prosody, variable stress, and reduced articulatory precision were also perceived. However, deficits of the laryngeal system—most notably severe breathy vocal quality with periods of aphonia—appeared to be most significantly impacting intelligibility and naturalness. As noted in Case 1, it is difficult to discern whether reduced loudness and periods of aphonia were in fact present or may have been an artifact of the telehealth platform (see Table 2).

Objective Evaluation

Objective evaluation differed from the perceptual findings. Speech rate was within normal limits in reading; however, speech rate is often slower in conversation (Huber, 2007; Huber & Darling, 2011). Utterance length was reduced (9.46 syllables), resulting in fewer breath pauses at major syntactic boundaries and more at minor boundaries. On the positive side, all of the breath pauses occurred at syntactic locations. These data could be interpreted to suggest an impairment in the respiratory subsystem. However, normal utterance length and breath pausing patterns are dependent on both intact respiratory function and effective vocal fold valving. Thus, when coupled with the perceptual ratings of severe breathiness and periods of aphonia, these data suggest that laryngeal valving is likely impaired, resulting in loss of pressure and lung volume during vocalization, leading to reduced utterance lengths. Thus, it appears that, in this case, the primary speech deficits are driven mainly by changes to the laryngeal system, although involvement and impairment of the respiratory system and its impact on speech dysfunction cannot be ruled out.

Objective evaluation also identified a reduced maximum F0 (280 Hz), an increased mean F0 (160 Hz), and an increased F0 variability (48 Hz). These data reveal a reduced overall pitch range and difficulty with pitch control (Boone et al., 2005), supporting the perceptual findings of monotonous prosody and variable stress. These abnormal acoustic findings provide further support for changes to the laryngeal system.

Putting It Together

Unlike Case 1, the perceptual and objective data for this case suggest that underlying laryngeal pathophysiology is a primary concern. While this patient's speech is severely impacted by deficits across several subsystems (i.e., respiratory, laryngeal, orofacial, prosodic), deficits in the laryngeal system appear to be impacting speech intelligibility and naturalness the most. Therefore, a therapeutic approach targeting loudness with focus on improved laryngeal valving may be the most effective starting point. While this may lead to improvements across speech subsystems, treatments more specifically targeting other speech deficits (e.g., respiratory support or articulation) may also be beneficial. Additionally, an endoscopic evaluation is recommended to determine the potential contribution of laryngeal pathophysiology (e.g., vocal fold atrophy) on dysarthria.

Tracking improvement in treatment will be challenging in this case given the suspected severe involvement of the laryngeal system, which is difficult to quantify via

Table 2. Case 2: Objective and perceptual measures of motor speech obtained from telehealth evaluation.

Measure	Patient	Norms, *M* (*SD*)
Objective measures		
Speech rate	4.24 syllables/s	4.6 (0.18) syllables/s
Utterance length	9.46 syllables[a]	13.2 (1.01) syllables
No. of breath pauses	12	13.4 (2.45)
% of pauses at major boundaries	41.7%[a]	67.2% (7.8)
% of pauses at minor boundaries	58.3%[b]	32.1% (6.4)
% of pauses at unrelated boundaries	0%	0.8% (1.7)
DDK rates	/pʌ/ = 3.8[a]	/pʌ/ = 6.3 (0.7)
	/tʌ/ = 4.0[a]	/tʌ/ = 6.2 (0.8)
	/kʌ/ = 4.0[a]	/kʌ/ = 5.8 (0.7)
	/pʌtʌkʌ/ = 4.8	/pʌtʌkʌ/ = 5.0 (0.7)
Mean F0	160 Hz[b]	126.7 (27) Hz
F0 minimum	113 Hz[b]	82.6 (11) Hz
F0 maximum	280 Hz[a]	363 (103) Hz
F0 variation	48 Hz[b]	>25 (8) Hz
Perceptual measures		
Vocal quality	Breathy	
Loudness	Inadequate	
Pitch range	Inadequate	
Rate	Speed: slow	
	Pace: variable	
Articulatory precision	Imprecise	
Resonance	Hypernasal	
Prosody	Intonation: monotonous	
	Stress: variable	
Fluency	Neurogenic stuttering: no	
	Palilalia: no	
% Overall severity	85.3%	
Dysarthria type	Hypokinetic	

Note. DDK = diadochokinetic; F0 = fundamental frequency.
[a]Below normal range. [b]Above normal range.

telehealth. Regular assessment with a combination of objective measures including utterance length, pausing patterns, and VAS ratings will allow for the most comprehensive way to quantify therapeutic gains.

Case 3: 1-Year History of Multiple System Atrophy-Cerebellar Subtype

Perceptual Evaluation

Perceptual evaluation revealed a moderate ataxic dysarthria, with a moderately slow and variable rate of speech, variable prosody, and equal and excess stress. Frequent and irregular pauses were also noted, as well as moderate–severe articulatory breakdowns—distortions and deletions of consonants and vowels—occurring predominantly on multisyllabic words, as well as telescoping of syllables in multisyllabic words. Irregular pausing and imprecise articulation were also perceived during DDK tasks. In this case, irregular articulatory breakdowns contributed most significantly to reduced intelligibility at times; however, changes in rate and timing appeared to be most significantly impacting naturalness (see Table 3).

Objective Evaluation

Objective evaluation identified a short utterance length (10.58 syllables/s), a markedly slow rate of speech (2.95 syllables/s), and slow DDKs (4.2–4.8 syllables/s). Additionally, there was an increased number of pauses produced at minor syntactic boundaries (54.5%) and fewer breaths at major boundaries (45.5%); however, no pauses were produced at inappropriate boundaries. Minimum F0 and maximum F0 were within normal limits, indicating an adequate F0 range (112–400.76 Hz), and F0 variation was also within normal limits (33 Hz).

Putting It Together

The objective measures of slow rate during speech and DDK tasks bolster the subjective perception of a slow and variable rate of speech. The slow rate and irregularity of DDKs is an important finding in this case—as it identifies the key components of and lends support for a diagnosis of ataxic dysarthria (Duffy, 2020).

Additionally, the objective finding of an increased number of pauses at minor syntactic boundaries support the perceptual identification of frequent and irregular pausing. Together, these data provide a basis for a treatment approach, which targets improving the control and regularity of rate and timing for enhanced speech naturalness. In particular, the frequency and irregularity of pauses and increased number of pauses at minor boundaries suggest poor respiratory coordination for speech. Therefore, focusing on increasing respiratory coordination for speech by placing pauses at

Table 3. Case 3: Objective and perceptual measures of motor speech obtained from telehealth evaluation.

Measure	Patient	Norms, *M* (*SD*)
Objective measures		
Speech rate	2.95 syllables/s[a]	4.6 (.18) syllables/s
Utterance length	10.58 syllables[a]	13.2 (1.01) syllables
No. of pauses	11[a]	13.4 (2.45)
% of pauses at major boundaries	45.5%[a]	67.2% (7.8)
% of pauses at minor boundaries	54.5%[b]	32.1% (6.4)
% of pauses at unrelated boundaries	0%	0.8% (1.7)
DDK rates	/pʌ/ = 4.8[a]	/pʌ/ = 6.3 (0.7)
	/tʌ/ = 4.6[a]	/tʌ/ = 6.2 (0.8)
	/kʌ/ = 4.2[a]	/kʌ/ = 5.8 (0.7)
	/pʌtʌkʌ/ = 6.0	/pʌhtʌkʌ/ = 5.0 (0.7)
Mean F0	100 Hz	126.7 (27) Hz
F0 minimum	112 Hz	82.6 (11) Hz
F0 maximum	400.76 Hz	363 (103) Hz
F0 variation	33 Hz	>25 (8) Hz
Perceptual measures		
Vocal quality	Harsh	
Loudness	Inadequate	
Pitch range	Inadequate	
Rate	Speed: slow	
	Pace: variable	
Articulatory precision	Imprecise	
Resonance	Hypernasal	
Prosody	Intonation: variable	
	Stress: equal and excess	
Fluency	Neurogenic stuttering: no	
	Palilalia: no	
% Overall severity	66.2%	
Dysarthria type	Ataxic	

Note. DDK = diadochokinetic; F0 = fundamental frequency.
[a]Below normal range. [b]Above normal range.

more appropriate locations may facilitate a more even rate and improve naturalness.

Finally, the perceptual finding of imprecise articulation in conversational speech and during DDK tasks is an important one, although it cannot be easily quantified via objective measures. Given its role in reducing intelligibility, improving articulatory precision may be another appropriate treatment target for this patient. Since articulatory precision cannot be easily quantified but has a large impact on overall intelligibility and severity, measuring overall speech severity using a VAS may be an appropriate method to track potential improvement. To track change over time, utilizing a VAS measure of severity together with measures of speech rate and pause frequency and location will provide the greatest insight into the presence and mechanism of therapeutic change.

Conclusions

The aim of this tutorial was to describe objective measures that can be easily obtained in real time and from recordings of speech telehealth evaluations conducted via popular web-based interfaces, and to demonstrate how these can be used as an adjunct to perceptual ratings to enhance the quality and utility of telehealth evaluations of dysarthria. Each of the described measurements is not without limitation; however, when taken together, they provide an objective approach to interpreting telehealth speech findings. In order to reliably utilize objective measures, evaluation protocols must be standardized within and across patients. This is critical in order to make comparisons to normative data and track change over time, ensuring that change is a result of patient function, rather than changes in evaluation and measurement procedures. A standardized protocol is presented in Appendix A.

Clinicians should use objective measures in combination with subjective measures to obtain the most comprehensive understanding of a patient's motor speech function. Determination of dysarthria type and severity will likely be heavily weighted on the clinician's overall perception of deviant speech characteristics, intelligibility, and naturalness. However, relying on the subjective assessment alone can lead to diagnostic error, and this may be exacerbated in the telehealth modality where technological factors (like device settings such as audio gain) may impact the clarity of the signal and clinicians' certainty about their auditory perceptions. As in our face-to-face evaluations, the addition of objective measures of motor speech into the clinical evaluation provides a method to concretely identify particular subsystem deficits and facilitate the selection of specific treatment targets. We have outlined a number of measures that can easily be obtained during evaluations in real time during conversational tasks, reading of "The Rainbow Passage," or other motor speech evaluation tasks. Given that this is a tutorial, reliability was not formally assessed; however, objective and perceptual ratings were generally consistent across three clinicians. Empirically evaluating the reliability of these measures in real time in the telehealth modality is an important area of future research.

Telehealth is a growing service delivery model for SLPs. While essential during the COVID-19 pandemic, telehealth will continue to expand as an important service delivery modality, particularly for older adults with neurological conditions and physical disabilities that limit access to clinical settings. Therefore, it is imperative that we build the evidence base to help improve and refine our evaluation and treatment approaches for motor speech disorders via telehealth. Future studies are needed, which reflect the real-world challenges that clinicians are facing during the COVID-19 pandemic and that highlight approaches that allow for the valid and reliable measurement of motor speech outcomes via telehealth.

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Appendix A

Example of a Standardized Perceptual Motor Speech Evaluation

Speech subsystem	Instruct the patient to do the following tasks
Respiratory	Take a brisk sniff in through your nose. Pant like a dog (provide prompts for speed and regularity as needed). Hold out /a/ for as long as possible. Shout as loudly as you can *"Hey you!"*
Laryngeal	Glide from lowest note to highest note. Glide from highest note to lowest note. Show me your prettiest singing voice. *Say*: "Today is a beautiful today." Now, whisper it.
Velopharyngeal	*Say*: "Make me a Hong Kong Cookie." *Say*: "Buy Bobby a Poppy." Now plug your nose and say that sentence again.
Orofacial	Repeat these words and sentences after me*:* i) Tornado, ii) Snowman, iii) Impossibility, iv) Catastrophe, v) Gingerbread, vi) Television, vii) In the summer they sell vegetables, viii) The shipwreck washed up on the shore, ix) Please put the groceries in the refrigerator, x) The valuable watch was missing. *Diadochokinetic Rate Instructions: Say*: "Take a breath and repeat /pʌpʌpʌpʌpʌ/ for as long and steadily as you can. Provide a 2- to 3-second demonstration. Repeat each sound for 3 trials, timing the patient for 5 seconds each time. Repeat with /tʌ/, /kʌ/, and /pʌtʌkʌ/."
Additional tasks to assess all subsystems	*The Rainbow Passage*: Instruct the patient to read this passage aloud at a comfortable loudness and pitch. *Spontaneous speech sample*: Ask the patient to speak about a topic of their choosing (e.g., "describe your typical daily routine" or "tell me about your family") for a minute.

Based on the work of Duffy (2020), Darley et al. (1969), and Kent et al. (1987) and as included in the work of Hegland et al. (2019).

Appendix B

VAS for Speech Severity Rating

Overall Speech Severity:

Please mark on the line below with a dot (.) how you would rate the individual's speech for overall speech severity. If the person's speech is considered normal, put the dot on the bottom of the scale on "normal." If the person's speech is very severely disordered, put the dot on "very severe." Otherwise put the dot somewhere between these two points as you feel is appropriate.

Very Severe

Normal

Appendix C

"The Rainbow Passage" Transcript With Syntactic Boundaries

When the sunlight [MINOR] strikes raindrops [MINOR] in the air [MINOR], they act like a prism [MINOR] and form a rainbow. [MAJOR] The rainbow [MINOR] is a division of white light [MINOR] into many beautiful colors. [MAJOR] These take the shape of a long round arch, [MINOR] with its path high above, [MINOR] and its two ends [MINOR] apparently beyond the horizon. [MAJOR] There is, [MINOR] according to legend, [MINOR] a boiling pot of gold [MINOR] at one end. [MAJOR] People look [MAJOR] but no one ever finds it. [MAJOR] When a man [MINOR] looks for something [MINOR] beyond his reach, [MINOR] his friends [MINOR] say he is looking for the pot of gold [MINOR] at the end of the rainbow.

(expected total number of syllables = 127)