Telerehabilitation, Virtual Therapists, and Acquired Neurologic Speech and Language Disorders

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ABSTRACT

Telerehabilitation (telerehab) offers cost-effective services that potentially can improve access to care for those with acquired neurologic communication disorders. However, regulatory issues including licensure, reimbursement, and threats to privacy and confidentiality hinder the routine implementation of telerehab services into the clinical setting. Despite these barriers, rapid technological advances and a growing body of research regarding the use of telerehab applications support its use. This article reviews the evidence related to acquired neurologic speech and language disorders in adults, focusing on studies that have been published since 2000. Research studies have used telerehab systems to assess and treat disorders including dysarthria, apraxia of speech, aphasia, and mild Alzheimer disease. They show that telerehab is a valid and reliable vehicle for delivering speech and language services. The studies represent a progression of technological advances in computing, Internet, and mobile technologies. They range on a continuum from working synchronously (in real-time) with a speech-language pathologist to working asynchronously (offline) with a stand-in virtual therapist. One such system that uses a virtual therapist for the treatment of aphasia, the Web-ORLA^{TM} (Rehabilitation Institute of Chicago, Chicago, IL) system, is described in detail. Future directions for the advancement of telerehab for clinical practice are discussed.

KEYWORDS: Telerehabilitation, telepractice, dysarthria, apraxia of speech, aphasia, virtual therapist, assessment, treatment

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Learning Outcomes: As a result of this activity, readers will be able to (1) discuss evidence supporting telerehab services for assessment and treatment of acquired neurologic speech and language disorders, and (2) describe the synchronous and asynchronous features of the Web-ORLA™ system.

The American Telemedicine Association defines telerehabilitation (telerehab) as "the delivery of rehabilitation services via information and communication technologies."[1] It further states that telerehab "encompasses a range of rehabilitation and habilitation services that include assessment, monitoring, prevention, intervention, supervision, education, consultation, and counseling." Although speech-language pathology services lend themselves to telerehab applications because of their focus on auditory and visual communication rather than physical contact and manipulation, telerehab is relatively new to the field of speech-language pathology. For example, it was only in 2001 that the American Speech-Language-Hearing Association (ASHA) designated "telepractice" as a topic for its Focused Initiatives, with position statements and technical reports being published in 2005.[2] Similarly, in 2006 the Canadian Association of Speech-Language Pathologists and Audiologists adopted policy statements accepting and guiding the use of telepractice.[2] Speech-language pathology organizations in many other countries have not yet developed policy statements on telerehab, despite the pressing need to increase services to rural areas.

Routine implementation of telerehab services into the clinical setting has been hindered by regulatory issues including licensure, reimbursement, and threats to privacy and confidentiality. For example, current medical and legal practices in the United States dictate that the location of the client determines the state in which the practitioner must be licensed.[3] Therefore, practitioners providing telerehab services to a client in another state must secure a license from the state where the client is located unless the state has exemption provisions within its licensure laws. Although professional requirements are likely similar from state to state, the lack of state license portability results in additional expense for the practitioner. Furthermore, states have different laws covering if and how telerehab can occur, with inconsistent adoption and nonuniformity of language regarding the use of telerehab.[3] Therefore, practitioners delivering telerehab services must be cognizant of the complex statutes, regulations, and policies of the state where the client resides.

With regard to reimbursement, Medicare does not reimburse for rehabilitation services delivered through telerehab because speech-language pathologists (SLPs) and audiologists (as well as occupational therapists and physical therapists) are not recognized as telerehab providers. In contrast, private insurance reimbursement for services delivered through telerehab may be possible, but it varies from state to state. Another consideration of importance to the practitioner relates to professional malpractice policies for services delivered through telerehab. These typically vary by carrier.[3]

The obligation to maintain patient privacy is a basic operating principle for SLPs and audiologists. Accordingly, telerehab technologies must be private, secure, and compliant with the Health Insurance Portability and Accountability Act of 1996. Expressed privacy policies of some commercial Voice over Internet Protocol (VoIP) and videoconferencing technologies that may be used for telerehab (e.g., Skype and others) may not translate to actual practice.[4] Practitioners need to be aware of potential risks to privacy and confidentiality, determine whether the benefits of using telerehab outweigh the potential risks, and fully inform the client of these potential breaches to confidentiality. Practitioners also need to take appropriate steps to implement safeguards to protect privacy and confidentiality including the following: strong password protection; authentication protection for access to personal health information; dedicated use of the computer or VoIP system for telerehab; virus protection and use of virus-free computers; encryption protocols that protect the transmission of video and audio data; and use of audit controls to record how often data are accessed by or released to internal and outside entities.[4]

Despite these barriers to clinical implementation of telerehab services, technological advances have increased the potential availability of these services and the ease with which they can be applied. Concurrent with these advances is a growing body of research regarding the use of telerehab applications in speech and language pathology with increasing evidence supporting telerehab as a valid and reliable vehicle for delivering speech and language services. In this article, we review the evidence as it relates to the assessment and treatment of acquired neurologic speech and language disorders in adults. Pioneering early work used telephone and television applications[5–7] and a satellite-based videoconferencing system[8] to assess and treat patients with motor speech disorders and aphasia. However, we focus on studies that have been published since 2000, and which have used more advanced technologies. These studies represent a progression on several fronts stemming from advances in computing, Internet, and mobile technologies. We describe telerehab applications for assessment and treatment that range on a continuum from working synchronously (in real-time) with a SLP to working asynchronously (offline) with a stand-in virtual therapist. Finally, we discuss future directions for the advancement of telerehab for clinical practice. Whereas ASHA uses the term "telepractice" to be inclusive of services provided in both educational and healthcare settings,[2] in this article we use the term "telerehabilitation" because we focus solely on services within the healthcare environment.

TELEREHAB AND ACQUIRED NEUROLOGIC SPEECH DISORDERS

Assessment

Studies have been undertaken to ensure that clinically valid and reliable assessments of motor speech disorders can be performed from a distance, with implications for diagnosis, for ongoing monitoring of progress, and/or maintenance of skills. Many of these studies have been conducted at the University of Queensland, Australia, where investigators compared face-to-face assessments with assessments that used an online custom built personal computer (PC)-based multimedia videoconferencing system. Using real-time videoconferencing over a 128 kbit/s Internet connection, the examining SLP at one site could view the participant with dysarthria at a second site, and vice versa. Additionally, store-and-forward video and audio banking at the participant's site allowed real-time video images and audio data to be captured, compressed, stored, and later forwarded to the examining SLP.

In the first pilot study, 19 speakers with dysarthria resulting from a variety of etiologies, including traumatic brain injury (TBI), hypoxic brain injury, stroke, and Parkinson disease (PD) were assessed in both the telerehab environment described above and a face-to-face environment.[9] A different SLP evaluated the participant in each environment simultaneously. Testing included the Frenchay Dysarthria Assessment (FDA),[10] the Assessment of Intelligibility of Dysarthric Speech,[11] perceptual analysis from a 2-minute conversation and from reading aloud of a standard passage, The Grandfather Passage,[12] and an overall rating of the severity of the dysarthria. Most measurements made in the telerehab environment fell within clinically acceptable criteria; however, several ratings of the FDA were not comparable between environments and the authors suggested that intraspeaker variability may have impacted these results. Additionally, technical issues may have influenced results, particularly those associated with ratings completed from video files. Technical issues included poor positioning of the camera, lack of zoom focus, and inadequate lighting and background contrast.[9]

When these technical issues were addressed in a larger follow-up study of 24 participants with a variety of different dysarthrias, good strength of agreement between the face-to-face and telerehab assessment methods was found.[13] In addition, participants reported high overall satisfaction with the telerehab environment.

Another study from the same research group using the same telerehab equipment focused specifically on demonstrating valid and reliable assessments of speech and voice in individuals with PD and hypokinetic dysarthria.[14] The study included 61 participants at various stages of PD[15] (i.e., 48 at stages I and II;

13 at stages III and IV) and with varying severities of hypokinetic dysarthria (41% mild; 48% moderate; 11% severe). Participants were randomly assigned to either a face-to-face or telerehab assessment environment. Once again, the online assessments were conducted via a PC-based videoconferencing system with store-and-forward capabilities, operating on a 128 kbit/s Internet connection.

Results indicated that the telerehab assessment of the disordered speech and voice associated with PD was generally reliable and valid.[14] For the majority of the perceptual and acoustic parameters, the face-to-face and online ratings were within acceptable clinical criteria. However, there were limitations during the real-time audio and video conferencing because of the small 128 kbit/s bandwidth.[14] This hindered the detection of fine motor movements and precision on the informal oromotor assessment due to the slow frame rate and pixilated image. These difficulties were more apparent with those with more severe dysarthria. Notably, the store-and-forward capabilities of the online system allowed for high quality audio and video recordings which helped minimize the audio-visual difficulties associated with real-time videoconferencing. Another problem was the presence of intermittent static in the audio recordings and occasional audio delays of up to 3 seconds over the videoconferencing link which affected communication interactions and turn taking. However, both the SLPs and participants were able to compensate for these delays quickly and effectively by waiting until the other had clearly finished speaking before replying. Overall, the online assessments were rated favorably by the participants, the application was user friendly, and the features of the application were conducive to assessment.[14]

Using the same custom-built telerehab conferencing system, 11 participants with acquired apraxia of speech were assessed on the Apraxia Battery for Adults-2 (ABA-2)[16] simultaneously via telerehab and face-to-face methods.[17] There was no significant difference between subtest scores of the ABA-2 obtained in the telerehab and face-to-face environments, suggesting that valid assessment over the Internet is feasible for persons with apraxia of speech. Like the previous studies, participants reported high overall satisfaction, comfort level, and audio and visual quality in the telerehab environment. However, SLPs reported some difficulty with assessing participants with severe apraxia of speech via the telerehab system and the authors suggested that those exhibiting severe apraxia of speech may be better suited for face-to-face assessment.[17]

Treatment

Telerehab treatment studies for acquired neurologic speech disorders have mostly investigated the delivery of the Lee Silverman Voice Treatment LOUD (LSVTLOUD), a Parkinson-specific approach that trains amplitude of speech (increased vocal loudness).[18,19] It also focuses on sensory awareness training of the amount, effort, and loudness required for normal voice. Individuals with PD are trained to "recalibrate" their motor and perceptual systems to improve self-monitoring and consistent use of the louder voice in daily communication. LSVTLOUD is delivered four times per week over 4 weeks, with each session lasting 50 to 60 minutes. In addition, there are daily homework and carry-over assignments for the entire month of therapy. Improvements in vocal loudness, quality, and speech intelligibility have been reported following delivery of LSVTLOUD in the traditional face-to-face modality with these results maintained up to 2 years following treatment.[18–23]

Given the intensity of LSVTLOUD, and the inherent barriers to access to treatment for persons with PD including mobility and fatigue problems, the need for telerehab services is potentially great.[24] Various forms of synchronous and asynchronous technologies either as alternatives to or in combination with face-to-face delivery of LSVTLOUD have been investigated.

Tindall et al used videophones to deliver LSVT remotely to the homes of 24 participants with PD and hypokinetic dysarthria.[25] They reported significant increases in sound pressure levels (SPL) with treatment for measures of sustained vowel phonation, reading, monolog, and picture description. Participant satisfaction with the use of the videophones was high.

However, limitations to this technology included difficulty in accurately recording SPL and vocal frequency, which are integral elements of the LSVT procedures. The SLP must be able to monitor the participant's vocal loudness (SPL) during all treatment tasks to aid calibration.

Howell et al acknowledged similar difficulties in delivering LSVT to three people with PD using a web camera and videoconferencing via Skype.[26] To solve the issue of measuring SPL, participants completed three sessions per week via Skype, and received one session per week face to face, during which time accurate vocal SPL values were recorded. Posttreatment improvements in mean SPL were noted on sustained vowel phonation, reading aloud, and monolog tasks, and these improvements were comparable to those obtained in previous face-to-face studies.

Theodoros et al solved the issue of monitoring vocal loudness during treatment in a different way.[27] They enhanced their custom PC-based videoconferencing system with an acoustic speech processor that allowed the SLP to view and sample in real-time, the calibrated average measures of SPL (all measured as dB-C), fundamental frequency (Hz), and duration (s) during the daily tasks and speech loudness drills. In a pilot study, 10 participants with mild-moderate PD and hypokinetic dysarthria received online delivery of LSVT. Results included significant improvements in mean SPL on sustained vowel phonation, reading and monolog tasks, significant improvements in maximum fundamental frequency range, and improved perceptual measures of pitch and loudness variability, loudness level, and breathiness. Additionally, high participant satisfaction was reported with the online system.[27]

A larger single-blinded, prospective, randomized controlled noninferiority online trial compared online and face-to-face LSVT.[28] A total of 34 participants with PD and hypokinetic dysarthria were randomly assigned to each treatment environment. The online LSVT was successfully delivered and clinically effective in improving the speech and voice of people with PD. Participants treated in the online environment showed comparable treatment outcomes on the acoustic and perceptual measures to those treated face to face.[28] In addition, a high level of participant satisfaction with regard to the online treatment sessions was achieved overall.[28]

It should be noted that all treatment sessions in the studies described, whether online or face to face, were conducted in a research laboratory setting. Only a single-case study has demonstrated the important next step of remote application in the "real world" at either the participant's home or within a community health center.[29] Current research is being conducted to establish the feasibility of delivering LSVT to people in their homes using a mobile version of the system and wireless connectivity.[24]

The studies demonstrate that telerehab treatment is promising and cost effective for both the person with PD and their caregivers.[25,30] However, in all these studies, the SLP must be present during every treatment session. Telerehab programs that allow participants to receive treatment sessions without the presence of a SLP at every session would increase cost effectiveness. To this end, Halpern et al reported on the development of software that incorporated the essential elements of LSVT and allowed the person with PD to practice independently.[31] Sixteen individuals with PD received half of their sessions at home using the software and the remaining sessions in the clinic face to face. Positive outcomes that were similar to previously published data were obtained both immediately posttreatment and at a 6-month follow-up.[31]

TELEREHAB AND ACQUIRED NEUROLOGIC LANGUAGE DISORDERS

Assessment

Studies evaluating the feasibility, validity, and reliability of administering language assessments to persons with acquired neurologic language disorders have compared results from face-to-face assessments with those of telerehab assessments. Across studies, different language assessment procedures have been used with participants that include persons with aphasia, Alzheimer disease, and other cognitive-communication disorders. In general, equivalence of the two assessment environments has been demonstrated, with some concerns raised that severity of the language disorder or associated cognitive impairments might impact the telerehab environment.

For example, Georgeadis et al[32] administered the standardized story retell procedure[33] in both face-to-face and videoconference-based telerehab settings to determine if performance on the assessment or subjective feedback from the participants differed between settings. Participants included 14 individuals with a left cerebrovascular accident (CVA), 14 with a right CVA, and 12 with TBI. They listened to a digitized prerecorded story accompanied by a series of black-and-white line drawings illustrating the story. Then participants were asked to retell the story in their own words, given a display of all of the drawings together. Responses were scored for percent information units,[34] and a survey tool was used to probe participant's level of satisfaction and willingness to use telerehab services in the future. The videoconferencing equipment was operated at a high bandwidth of 10 Mbit/s to ensure the best available audio and video quality.

There was no significant difference in performance across settings for all participants, and differences between face-to-face and telerehab settings were not significant for any participant group.[32] Interestingly, the left and right CVA groups performed the same or better in the telerehab setting compared with the face-to-face setting. In contrast, the TBI group performed more poorly in the telerehab setting. The authors suggest that impaired attention may have adversely affected the performance of the TBI group in the telerehab setting, and that telerehab may not be applicable to those with severe cognitive-communication impairments.[32] In a follow-up publication using the same dataset, the authors found that age, education, technology experience, and gender did not have a significant effect on participant performance in the technology versus face-to-face settings.[35] Overall these results, together with the participants' expressed interest in using videoconferencing, provide support for telerehab as a viable alternative mode for assessing language skills in adults with neurologic communication disorders across a range of etiologies.

Some studies have focused specifically on one type of etiology and/or language disorder. Palsbo conducted a randomized double-crossover agreement study of remote versus face-to-face assessment of 24 stroke patients with aphasia.[36] Participants were assessed with a subset of tasks from the Boston Diagnostic Aphasia Examination (BDAE)[37] by two SLPs who were blind to each other's scores. The videoconferencing equipment was operated over a 384 kbit/s connection. Percent agreement ranged from 92 to 100% for each functional communication measure, regardless of the assessment site, suggesting that videoconferencing is equivalent to a face-to-face encounter. However, Palsbo acknowledged that participants predominantly had milder functional communication deficits which may have biased the results of the study.[36]

Other studies focusing specifically on aphasia randomly assigned participants to either a face-to-face led or telerehab-led assessment.[38,39] For the telerehab assessment, copyright permission was obtained for the BDAE-3 Short Form,[37] including the 15-item short form of the Boston Naming Test (BNT),[40] and the exact electronic digital file was incorporated into the software program. Participants used a touch screen to indicate their choice of images; their response would then appear on the clinician's computer along with the time taken to respond. The bandwidth of this custom built telerehab system was 128 kbit/s.

The BDAE-3 scores obtained in the two environments were not significantly different, and subjects reported high overall satisfaction, comfort level, and audio-visual quality in the online environment.[39] Given concerns about the impact of severity on the accuracy of a telerehab assessment, data were further analyzed. Of the 32 participants, 10 had a mild aphasia, 10 had a moderate aphasia, and 12 participants were rated as having a severe aphasia. The severity of the aphasia made the assessment via telerehab more challenging. For example, audio break-up over the videoconference affected the conversational/expository speech subtest and the BNT. It was not always clear whether participants were exhibiting reduced auditory comprehension or merely experiencing difficulty in hearing the question or comment. Additionally, the SLP could not always identify participants' error and paraphasic responses on the BNT to provide the appropriate stimulus and phonemic cues as needed. Regardless of these challenges, aphasia severity did not impact the validity and reliability of the assessment—across the three severity levels, there were high levels of agreement between the telerehab and face-to-face environments.[39]

A pilot study of language assessments via telerehab has also been conducted with participants with mild Alzheimer disease.[41] The test battery included the picture description task of the BDAE, the BNT, and subtests of the Multilingual Aphasia Examination.[42] Participants received the standard language tests under two conditions, face-to-face and via a 384-kbit/s teleconferencing line that allowed for real-time interaction between the clinician and the participant. There was no significant difference on performance between the two testing environments, and consistent with other investigations, participants reported excellent satisfaction with the telerehab environment.[41]

All the reported studies have conducted the assessments in well-controlled, quiet environments with technical staff available to immediately provide assistance with equipment problems. Future research should evaluate the use of telerehab services in an uncontrolled setting such as the home where logistical difficulties may interfere with the assessment procedures, for example, doorbell ringing, dog barking, or computer breaking down.[32]

Treatment

In contrast, most of the telerehab treatment studies of acquired neurologic language disorders have provided therapy to participants in their own home environment. These treatment studies have been confined largely to the management of aphasia. Using a custom videoconferencing system, the feasibility of in-home telerehab of patients with aphasia was explored in three participants.[43] The treatment targeted single word auditory and written comprehension and production (e.g., repetition, oral reading, copying, rhyming, and word-to-picture matching). Each participant received 12 1-hour telerehab sessions over 6 weeks, delivered by the same SLP. Results indicated clinically relevant improvements on confrontation naming of trained items and high scores on a satisfaction questionnaire.[43]

There are other descriptive reports of in-home telerehab using free videoconferencing systems such as Skype and ooVoo video chat.[44,45] For example, five clients with mild-to-moderate aphasia participated in a 2-week protocol of Constraint-Induced Language Therapy (CILT), using loaned Apple MacBook laptop computers embedded with real-time cameras and microphones.[45] In CILT, two participants simultaneously interact over a card game much like Go Fish, and are required to use only oral language to request cards from each other or to respond to requests from their partner. Intensive practice is required, and although the ideal dosage has not been established, several protocols specify that treatment is conducted 4 days per week for 3 hours a day.[46] Analysis of individual subject data indicated overall improvements in three of the five subjects including improvements on the Western Aphasia Battery Aphasia Quotient[47] and an increase in the number of propositions included in the retelling of the Cinderella story.

For telerehab to be cost effective, participants need to independently practice their treatment tasks without the presence of the SLP. This is one of the key factors identified by Mortley et al as essential for the remote delivery of services to persons with aphasia.[48] They state that "the system should be efficient in terms of the ratio of therapist time required and the amount of therapy practice time obtained."[48(p.195)] Other factors that they list are that (1) the system must be accessible and easy to use so the person with aphasia can independently complete the exercises, forward results to the SLP, and ask for new therapy tasks; (2) the SLP should be able to access information remotely about the person with aphasia's performance and make appropriate changes to the therapy; and (3) the therapy should be efficacious with regard to both the language impairment and functional communication.[48]

With these factors in mind, Mortley et al investigated a word retrieval therapy delivered remotely using specially designed software installed on a computer in the participant's home and connected to the therapist's computer via the Internet. A case series study with seven participants with chronic aphasia was conducted. They collected usage data, language data from pretreatment to posttreatment, and qualitative data from semi-structured interviews regarding the acceptability of this mode of therapy. All participants used the software for the entire 27 weeks of treatment. The average number of hours of practice per week was 2 hours and 45 minutes (range 1 hour 43 minutes to 3 hour 46 minutes).

Over the 6-month treatment period, only 3 to 6 remote sessions with the therapist, lasting ~2 hours each, were scheduled. During this time, the SLP downloaded results, phoned the participant to discuss progress, assigned new exercises, and transferred them to a secure server. Additional home visits were required for three participants to solve technical issues such as replacing the modem. No face-to-face therapy took place. Participants demonstrated significant improvements in word retrieval of objects and actions.[48] Additionally, all participants described a sense of increased autonomy and reported that this mode of therapy had facilitated more intensive practice.[49] They attributed their increased functional communication not only to language improvements but also to increased confidence and self-esteem.[49]

We have also developed a custom telerehab system called Web-ORLA™ (described in detail below in the section "TELEREHAB WITH A VIRTUAL THERAPIST") that adheres to the factors outlined by Mortley et al and allows cost-effective synchronous and asynchronous delivery of the Oral Reading for Language in Aphasia (ORLA™, Rehabilitation Institute of Chicago, Chicago, IL) treatment. In ORLA, the participant with aphasia systematically and repeatedly reads aloud sentences and paragraphs, first in unison with the SLP and then independently.[50,51] Previous studies have demonstrated improvements in auditory comprehension, oral expression, reading comprehension, and written expression when ORLA is delivered in person by a SLP.[50–52] Additionally, there are no significant differences in outcomes when ORLA is delivered in person by a SLP versus delivery by computer software.[53] Most recently, a study of Web-ORLA™ showed that delivery of ORLA™ via the custom telerehab system was feasible as well as efficacious for some individuals with aphasia.[54,55] Participants with aphasia received 9 hours of treatment a week for 6 weeks (i.e., 3 × 30 minutes/day or 2 × 45 minutes/day, 6 days a week). There was a statistically significant improvement in language performance in auditory comprehension, oral expression, and written expression, and these changes were maintained over time.[55] Analysis of individual subject data indicated that almost 80% of participants receiving Web-ORLA™ made a clinically significant change in at least one language modality.[55]

In summary, studies show that telerehab can be a valid and reliable vehicle for delivering speech and language services. However, extraneous factors that can affect assessment validity and treatment fidelity are important to consider. These include the following:

- Type and severity of the disorder.
- Impaired attention and motivation affecting treatment compliance.
- Impaired motor function or other comorbidities accompanying the disorder.
- Lack of access to effective technology solutions that are stable, easy to set up and use, and affordable.
- SLP availability for telerehab.
- Validity, quality, and availability of remote real-time measurements due to factors limiting access, bandwidth, and fidelity: including privacy and security, network latency, device capabilities, environmental noise, and instrument variability.

TELEREHAB WITH A VIRTUAL THERAPIST

The Web-ORLA™ system is designed to overcome and mitigate some of the factors that can affect treatment by adopting a uniquely integrated approach to synchronous and asynchronous telerehab.[54,56] The system consists of separate SLP and participant applications that communicate with each other through the

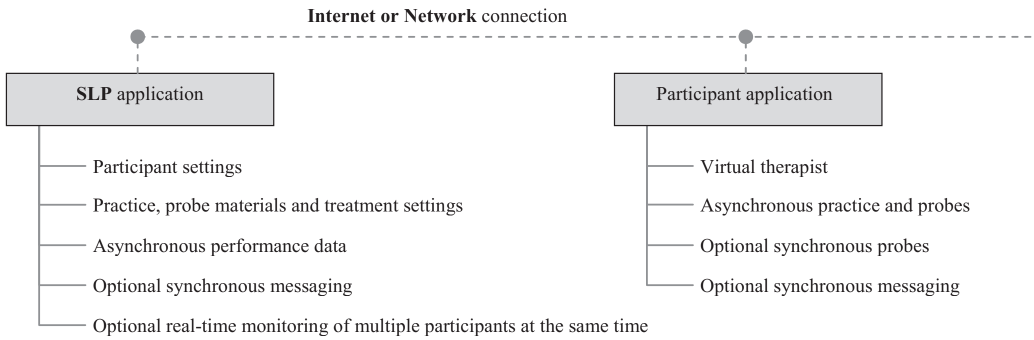

Figure 1 Diagram of the Web-ORLA™ telerehabilitation system consisting of separate SLP and participant applications that communicate with each other through the Internet or a private local network. SLP, speech-language pathologist.

Internet or a private local network (see Fig. 1). In this section, we describe some of the features of the system followed by a brief discussion of efforts toward developing yet more inclusive and flexible approaches for telerehab.

Asynchronous Treatment with a Virtual Therapist

Extensive support for asynchronous treatment, that is, treatment that does not require the clinician and PWA to interact in real-time makes the Web-ORLA™ system suitable for participants with aphasia severities ranging from mild-moderate to severe. In the study described earlier, participants who practiced asynchronously with the system were able to receive more intensive treatment and to practice more than what would have been possible had they only practiced synchronously with a SLP.[54,55] The simplicity of the program interface—participants need only to press the space bar to move through the treatment steps—the sequenced and customizable nature of the sentence stimuli and treatment steps, and the asynchronous guidance that the system provides make Web-ORLA™ easy to use, even without a SLP present.

In contrast to typical telerehab approaches that provide treatment through videoconferencing only, Web-ORLA™ uses a "virtual therapist" to also provide asynchronous guidance at home. The virtual therapist is a three-dimensional animated agent that can speak with highly intelligible prerecorded speech.[57] Much like a SLP, the virtual therapist is available to read practice stimuli aloud, read in synchrony with highlighted text, repeat words and sentences, model oral-motor movements, and interactively provide cues and guidance through preassigned tasks. Because of the repetitive nature of the treatment, the virtual therapist's responses are kept short and focused on providing cues and guidance to maximize participant practice time and treatment intensity.

During treatment, participants read sentence and paragraph stimuli displayed on the screen out loud—first in unison with the virtual therapist and then independently (Fig. 2). This mirrors the original ORLA™ protocol in which participants systematically and repeatedly read sentences and paragraphs out loud with a SLP.[50–53] Participants work at their own pace, pressing the space bar to move between stimuli. The system maintains a detailed time-stamped log of all interactions and responses, including participant audio recordings, available to the SLP for postanalyses by store and forward; or in near real-time with a small latency, when both the SLP and participant are online.

Recently, we developed a new virtual therapist with visible speech based on a novel computational linguistic approach that efficiently models coarticulation, place, and manner of speech, speaking rate, and enunciation; rendering fine differences between visible sounds while preserving the naturalness and fluency of conversational speech.[58,59] The approach supports three-dimensional anthropomorphically

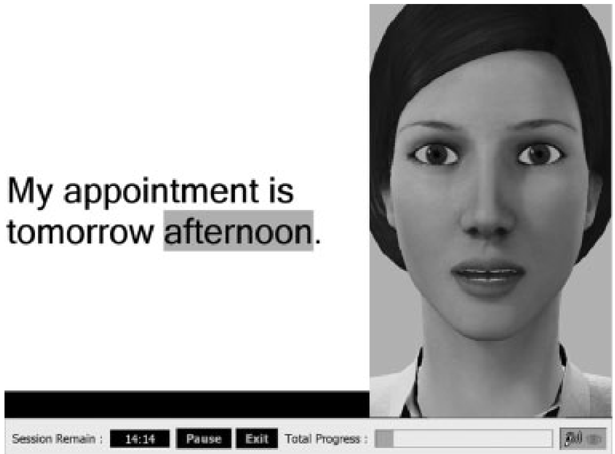

Figure 2 Web-ORLA™ screen with practice sentence seen by the participant. The virtual therapist (new version shown) provides cues, feedback, and encouragement in the same way a SLP provides ORLA treatment. In the example, the virtual therapist is reading the practice sentence aloud and modeling oral-motor movements in synchrony with highlighted text. Note that the ear icon in the bottom right corner of the screen is highlighted, indicating that the SLP is monitoring the session remotely by listening in. The eye icon is not highlighted, indicating that video monitoring is not being used. SLP, speech-language pathologist.

accurate animation at high temporal and spatial resolutions. Significantly, it works with most PCs, HTML5 compliant web browsers, and Android and iOS mobile applications—making possible the development of telerehab solutions that are pervasive, yet inclusive and supportive.[59,60] Previous versions of Web-ORLA™ featured a virtual therapist that synthesized visible speech from phoneme-level segments of motion capture data.[61] While fairly accurate, the approach was prone to artifacts, required significant computational resources, and worked only on select PCs, motivating us to develop the new virtual therapist.[†]

Synchronous Monitoring and Messaging with a SLP

While asynchronous support is necessary for independent practice, synchronous monitoring and communication are necessary for independent verification of participant progress and treatment compliance. When both participant and SLP are online, Web-ORLA™ allows the SLP to actively monitor the participant's progress, and if necessary, to provide additional support and intervention with two-way messaging that can be initiated by either party. In contrast to most telerehab approaches, Web-ORLA™ allows a single SLP to remotely monitor multiple participants simultaneously and independently whether in clinic setting or home, potentially providing additional flexibility and cost savings over working with a single participant at a time.[56,57]

To monitor multiple participants, the SLP's screen displays a list of all enrolled participants and whether they are logged in. From the list, the SLP can select to monitor up to four participants simultaneously with a text summary of each participant's progress streamed in real-time to the SLP's screen (Fig. 3). Most of the time participants work independently, while the SLP occasionally "checks in" on each participant individually by clicking on "ear" and "eye" icons below that participant's summary to listen to streaming audio and/or watch streaming video of the participant using the system.

† The previous virtual therapist has been integrated into a related aphasia therapy program, AphasiaScripts® that is available commercially. Web-ORLA™ exists as a research system only. As of this writing, the mobile, web, and PC versions of the new virtual therapist are available for collaborative research studies (see http://interactive.colorado.edu for more information), but not yet commercially.

Figure 3 Web-ORLA™ screen seen by the speech language pathologist. Names of participants are shown on the left of the screen. A watch window shows the synchronous real-time data for the selected participant including session length and current activity. Note that the eye and ear icons have been selected allowing the SLP to monitor the participant using real-time audio and video. By instead selecting the text, camera or microphone icons, the SLP can switch to full text, audio, and/or video messaging with the participant. A summary window provides additional information on treatment protocol and treatment progress. SLP, speech-language pathologist.

To further provide synchronous support if necessary, the SLP can interrupt and temporarily pause any participant's session and initiate a real-time two-way conversation using text, audio, and/or video messaging as appropriate. "Ear" and "eye" icons on the screen alert the participant when the SLP is available and monitoring the session. To initiate a two-way conversation with the monitoring SLP, the participant needs to simply click on one of the icons. Rather than using a separate stand-alone video conferencing solution, messaging features in Web-ORLA™ were developed as part of the application itself to ensure that the participants and SLP can access them easily and seamlessly.

Participant progress information available in real-time is also available asynchronously in formative and summative formats searchable by session, day, week, and arbitrary time periods. Daily practice logs provide detailed information on number and type of practice and probe sentences completed as well as practice time, allowing the SLP to asynchronously monitor progress, review, and score audio recordings of practice and probe sentences, provide oversight, and verify compliance without requiring costly in-person visits.

When we originally developed the Web-ORLA™ system, typical broadband network speeds were 768 kbit/s or less upstream and 1.5 Mbit/s downstream—in contrast to higher speeds available today. To accommodate these and even slower speeds, Web-ORLA™ works with multiple tiers of monitoring and messaging service (text, audio, and video data) depending on available bandwidth. The practice log is compressed and encrypted into a 3-kbit/s stream and the 16 kHz 16 bit sampled speech recordings of each participant are compressed into a 26-kbit/s stream. The synchronous text and voice-only messaging data are compressed into a separate 26 kbit/s stream. The optional synchronous video messaging data are captured using an off-the-shelf webcam and compressed into a 640-kbit/s stream or less. Video frames are transmitted 10 times per second when speech is detected and once every 60 seconds otherwise.

Future Directions

The varied and complex realities of telerehab—SLP availability, participant needs, technology limitations, access, confidentiality, state licensure requirements, and costs—suggest that more inclusive and flexible models for telerehab are needed. Hybrid approaches that combine synchronous and asynchronous telerehab in new ways that leverage the rapid advance and tumultuous adoption of computing, Internet, and mobile technology may provide optimal telerehab models.[62–64]

Participants (and SLPs) will increasingly expect solutions that work anywhere and everywhere, whether accessed remotely from home or locally in the clinic; and whether by tethered, mobile or wireless means. They will come to expect "smart" systems that seamlessly switch between synchronous and asynchronous use so that participants can receive treatment even when the SLP or network connection is not available. They will expect offline use to have supporting technologies that ensure that treatment remains effective and accommodates individual needs. They will expect solutions that encourage peer-to-peer support and build community.[65] And they will expect telerehab solutions that automatically adapt monitoring and oversight based on proximity, bandwidth, and privacy considerations, while ensuring data security.

For example, in the Internet centric world, they will expect online solutions that work in the "Cloud" (likely a secure private Cloud) and can be accessed from any HTML5 capable web browser through a secure connection. Such solutions would be similar to web-based e-mail and messaging and allow anywhere, everywhere access by simply logging in through a web browser.

In a mobile centric world, they will expect telerehab approaches that extend beyond PC solutions and work across a broad range of devices and access modalities. Securing such systems will be a challenge. In one scenario of localized-only use, participant and SLP devices might synchronize automatically and securely through a wireless or similar connection during office visits, but not communicate otherwise. In another scenario, consenting participants working in a group session may be able to communicate not only with the SLP but also with each other.

In ongoing research, we are working to extend our existing computer-based telerehab systems to this new reality. As part of a multi-year research study to investigate the effect of modulating cues, feedback and practice conditions on the clinical outcomes of individuals with chronic aphasia, we are redesigning a telerehab system for remote and localized use.[66] We recently completed prototype computer and mobile iOS versions of this system that we plan to pilot in the study in which treatment involves practicing dialog scripts.[67,68] Eventually, as envisioned, the system may also include opt-in social networking features that extend beyond traditional modes of telerehab.

As technology advances and research continues demonstrating positive outcomes from telerehab services to persons with neurologic speech and language disorders, we are optimistic that solutions to the regulatory challenges hindering the clinical implementation of telerehab services will not lag too far behind. The routine clinical use of telerehab services will offer a cost-effective approach that removes geographical barriers and improves access to care for those with acquired neurologic communication disorders.

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