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Telerehabilitation of Anomia in Primary Progressive Aphasia

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Abstract

Background—The efficacy of telerehabilitation-based treatment for anomia has been demonstrated in post-stroke aphasia, but the efficacy of this method of anomia treatment delivery has not been established within the context of degenerative illness.

Aims—The current study evaluated the feasibility and efficacy of a telerehabilitation-based approach to anomia treatment within the three subtypes of primary progressive aphasia (PPA).

Methods & Procedures—Each of the three telerehabilitation participants represented a distinct subtype of PPA. Following a baseline evaluation of language and cognition, a phonological treatment and an orthographic treatment were administered to all participants over the course of six months. One month after the end of treatment, a post-treatment evaluation began. All treatment sessions and the majority of the evaluation sessions were administered via telerehabilitation. Treatment effects were examined within each subject, and treatment effects were also compared between each telerehabilitation participant and a group of in-person participants who had the same subtype of PPA.

Outcomes & Results—All three telerehabilitation participants exhibited positive treatment effects. CGR (nonfluent/agrammatic variant PPA) and WCH (logopenic variant PPA) showed maintenance of naming for prophylaxis items in both treatment conditions, while ACR (semantic variant PPA) demonstrated increased naming of remediation items in the phonological treatment condition. Compared to in-person participants with the same subtype of PPA, each of the telerehabilitation participants typically showed effects that were either within the expected range or larger than expected.

Conclusions—Telerehabilitation-based anomia treatment is feasible and effective in all three subtypes of PPA.

Keywords

telerehabilitation; primary progressive aphasia; anomia

As the baby boomer generation transitions into old age, the number of aging patients with disabilities is rapidly increasing. This growth has resulted in an increased interest in telemedicine, i.e., the delivery of medical assessment and care via remote means. Telemedicine holds the promise of improved access to medical care, with the additional benefit of reduced cost. By using modern information and communication technologies, services can be delivered to clients who would otherwise be unable to receive them for reasons such as distance from a healthcare facility, lack of trained clinicians in a geographic area, or mobility impairments.

Initially, studies using telemedicine for communication disorders focused mainly on assessment. Several studies have compared remote language assessment with in-person assessment (Duffy, Werven, & Aronson, 1997; Georgeadis, Brennan, Barker, & Baron, 2004; Hill, Theodoros, Russell, Ward, & Wootton, 2009; Palsbo, 2007; Theodoros, Hill, Russell, Ward, & Wootton, 2008; Vestal, Smith-Olinde, Hicks, Hutton, & Hart, 2006; Wertz et al., 1992). Strong agreement between the two modes of assessment has been found in the population of individuals with post-stroke aphasia (Hill et al., 2009; Palsbo, 2007; Theodoros et al., 2008; Wertz et al., 1992), individuals with mild AD (Vestal et al., 2006), individuals with traumatic brain injury (TBI; Georgeadis et al., 2004), and those who have suffered a left- or right-hemisphere stroke (Georgeadis et al., 2004). Furthermore, it has been found that age, education, technology experience, and gender do not have a significant effect on participant accuracy in remote vs. in-person assessment settings (Brennan, Georgeadis, Baron, & Barker, 2004).

More recently, telerehabilitation has been shown to be effective in the treatment of speech and language disorders, including voice disorders (Constantinescu et al., 2010; Mashima et al., 2003; Theodoros et al., 2006; Tindall, Huebner, Stemple, & Kleinert, 2008), apraxia of speech (Lasker, Stierwalt, Spence, & Calvin-Root, 2010), and stuttering (Kully, 2000; O'Brian, Packman, & Onslow, 2008; Wilson, Onslow, & Lincoln, 2004). Telerehabilitation has also been utilized to train the production of personally relevant speech in participants with Broca's aphasia (Goldberg, Haley, & Jacks, 2012).

Recent telerehabilitation studies involving post-stroke aphasia have examined the efficacy of anomia treatment or lexical retrieval treatment (Agostini et al., 2014; Dechene et al., 2011; Fridler et al., 2012; Furnas & Edmonds, 2014). In the first of these studies, Dechene et al. conducted a telerehabilitation study involving three participants with anomia. Following treatment, the participants demonstrated more improvement for trained than for untrained items. In a study involving a crossover design and five participants with chronic aphasia and anomia, Agostini et al. (2014) found comparable positive effects of remote and in-person anomia treatment. Similarly, Fridler et al. (2012) compared remote and in-person delivery of anomia treatment in a study that involved a crossover design and eight participants with chronic aphasia. The participants' overall improvement, as measured by the aphasia quotient of the Western Aphasia Battery (WAB; Kertesz, 1982), was significantly higher following telerehabilitation. Furnas and Edmonds (2014) used telerehabilitation to deliver Verb Network Strengthening Treatment to two participants with chronic aphasia. The participants showed improvement in the retrieval of trained and untrained words during sentence

production, and they also showed generalization of treatment effects to the naming of untrained nouns and verbs.

Getz, Snider, Brennan, and Friedman (2015) demonstrated the viability of a telerehabilitation treatment for patients with acquired alexia. Two persons with aphasia and phonologic alexia participated in the study, which tested the administration of a treatment protocol previously shown to be successful for improving the reading of certain words in persons with phonologic alexia. Following the telerehabilitation treatment, both participants showed improved reading of trained words, but no improvement for untrained words. This study employed custom software similar to that used in the current study.

In summary, studies are beginning to emerge that indicate telerehabilitation-based approaches to anomia and alexia treatment can be effective in post-stroke aphasia. What has yet to be determined is whether telerehabilitation can be effective in treating the anomia that occurs in degenerative illnesses such as primary progressive aphasia (PPA). PPA is a clinical syndrome characterized by progressive language impairment (Mesulam, 1982). Other aspects of cognition, such as episodic memory and visuospatial skills, are relatively preserved during the initial phases of the illness. A prominent feature of PPA is word-finding impairment.

Three variants of PPA have been identified (Gorno-Tempini et al., 2011). Individuals with the nonfluent/agrammatic variant (nfvPPA) have effortful, halting speech with apraxia, and/or agrammatic language production. Impaired comprehension of syntactically complex sentences may also be present, while single-word comprehension and object knowledge are typically spared. Individuals with nfvPPA may have difficulty reading or spelling nonwords (phonological alexia or agraphia; Brambati, Ogar, Neuhaus, Miller, & Gorno-Tempini, 2009; Graham, 2014; Wilson et al., 2010). nfvPPA has been associated with tau-positive frontotemporal lobar degeneration in a majority of cases (FTLD-T; Hodges et al., 2004; Knibb, Xuereb, Patterson, & Hodges, 2006; Mesulam et al., 2008; Mesulam et al., 2014).

The semantic variant (svPPA) involves impaired confrontation naming and single-word comprehension deficits. Impaired object knowledge may be present, and difficulty reading or spelling words with irregular orthography (surface alexia or agraphia) may also occur (Gorno-Tempini et al., 2011). Repetition and speech production are typically spared. In a majority of cases, svPPA has been associated with ubiquitin and TDP-43 positive FTLD (FTLD-U or FTLD-TDP; Hodges et al., 2004; Knibb et al., 2006; Mesulam et al., 2014).

The logopenic variant (lvPPA) is characterized by impaired single-word retrieval and impaired repetition of sentences and phrases. Phonological speech errors (Gorno-Tempini et al., 2008), phonological alexia (Brambati et al., 2009), and phonological agraphia (Graham, 2014) may also occur, while surface agraphia is a less common deficit (Graham, 2014). Single-word comprehension, object knowledge, motor speech, and grammar are typically spared. In a majority of cases, people with lvPPA have been found to have an atypical form of Alzheimer's disease (AD; Mesulam et al., 2008; Mesulam et al., 2014; Rabinovici et al., 2008).

A number of studies have evaluated language treatment in individuals with PPA. Studies involving people with nfvPPA have found improvement as a result of treatment for agrammatism (Schneider, Thompson, & Luring, 1996), phonological processing deficits (Louis et al., 2001), apraxia of speech (Henry, Meese, et al., 2013), and anomia (Jokel, Cupit, Rochon, & Leonard, 2009; Marcotte & Ansaldo, 2010). Individuals with svPPA have benefited from treatment for deficits in object knowledge and concept knowledge (Bier et al., 2009; Bozeat, Patterson, & Hodges, 2004; Dewar, Patterson, Wilson, & Graham, 2008; Robinson, Druks, Hodges, & Garrard, 2008), and they have benefited from treatment for anomia (see Jokel, Graham, Rochon, & Leonard, 2014, for a review; also see Henry, Rising, et al., 2013). Those with lvPPA have been shown to benefit from treatment for dysgraphia (Tsapkini & Hillis, 2013) and anomia (Beeson et al., 2011; Henry, Rising, et al., 2013; Meyer, Snider, Eckmann, & Friedman, 2015; Newhart et al., 2009).

Anomia is a frequent target for therapy because it is common to all three variants of PPA (Gorno-Tempini et al., 2011), and because it occurs early during the illness (Westbury & Bub, 1997). Word-finding problems lead to increased communication difficulties and can lead to decreased independence. Treatment programs that improve word-finding abilities, or indeed delay the decline of word-finding abilities, could have a large impact on the lives of persons living with PPA and their families.

When an individual with PPA makes an error during a confrontation naming task, the error may be caused by difficulty accessing the semantic representation or by difficulty accessing the phonological representation. The semantic deficits and semantic paraphasic errors that occur within svPPA suggest that the former type of difficulty is more likely in this subtype (Hodges, Patterson, & Tyler, 1994; Mesulam et al., 2009; Neary et al., 1998). In contrast, the phonemic paraphasic errors that occur in lvPPA (Gorno-Tempini et al., 2008; Henry & Gorno-Tempini, 2010) and nfvPPA (Ash et al., 2010; Watt, Jokel, & Behrmann, 1997) suggest that the latter type of difficulty is more likely in these subtypes.

The current study included two types of treatment for anomia: a treatment that focuses on phonology, and an orthographic treatment that includes reading and writing tasks. In the phonological treatment, an auditorily-presented word occurs in conjunction with the corresponding picture, and the participant repeats the word. The goal of this treatment is to strengthen the phonological representations of the treated words, thereby facilitating access to these representations and bolstering the production of the treated words (see Figure 1a). In the orthographic treatment, the written word occurs in conjunction with the corresponding picture, and the participant reads the word out loud and transcribes it. The goal of this treatment is to strengthen the orthographic representations of the treated words, thereby facilitating access to these representations and bolstering the alternative, orthographic route to word production (i.e., the phonological representation can be accessed via the orthographic representation, rather than being accessed directly from the semantic representation; see Figure 1b).

In a recent study that utilized these phonological and orthographic treatments in a Norwegian-English bilingual participant with lvPPA (Meyer et al., 2015), orthographic treatment in English improved the maintenance of English written naming and the oral

naming and naming to definition of the corresponding items in Norwegian. In contrast, phonological treatment in English only had a marginal effect on the maintenance of oral naming in English. Based on these results, it was concluded that the orthographic treatment strengthened the orthographic and semantic representations of treated items, while the phonological treatment only appeared to strengthen the phonological representations of treated items. Thus, one could predict that the orthographic treatment would be more effective than the phonological treatment in svPPA, and that the phonological and orthographic treatments would both be effective in nvPPA and lvPPA, because both treatments would be expected to facilitate access to phonological representations. A within-subjects approach was employed in the current study, allowing both treatments to be tested in the same individuals.

In treatment studies for anomia in PPA, the goal has typically been the remediation of words that could not be named at baseline, rather than the prophylaxis of words that could be named at baseline (see Jokel et al., 2014). Nevertheless, three case studies have found positive effects of prophylactic treatment in PPA (Jokel, Rochon, & Leonard, 2006; Jokel, Rochon, & Anderson, 2010; Meyer et al., 2015). As described in the paragraph above, Meyer et al. (2015) found positive effects of prophylactic treatment in lvPPA. The other two studies focused on prophylactic treatment in svPPA (Jokel et al., 2006; Jokel et al., 2010). Compared to baseline performance, Jokel et al. (2006) found that naming of matched untreated items was significantly lower at post-treatment and during follow-up testing at 1 month and 6 months post-treatment. In contrast, naming of treated items did not decline significantly at any time point. Similarly, Jokel et al. (2010) found that post-treatment naming accuracy for treated items was significantly greater than accuracy for matched untreated items. As in the studies by Jokel et al. (2006, 2010), the current study included both prophylaxis and remediation items for each participant, when it was feasible.

The current study evaluated the feasibility and efficacy of a telerehabilitation-based approach to anomia treatment in three individuals with PPA. Each of these individuals represented a distinct subtype of PPA. Following a baseline evaluation of language and cognition, the phonological and orthographic treatments were administered over the course of six months. One month after the end of treatment, a post-treatment evaluation began. The one-month delay was included in order to ensure that any observed treatment effects were not due to the short-term benefits of recent treatment sessions.

All treatment sessions and the majority of the evaluation sessions were administered via telerehabilitation. Treatment effects were examined within each subject, and treatment effects were also compared between each telerehabilitation participant and a group of in-person participants who had the same subtype of PPA.

Method

Participants

Fourteen individuals completed in-person treatment, and three participants completed remote treatment. See Tables 1 through 3 for demographic information. The remote participants were assigned to this method of treatment delivery after enrolling in the parent

treatment study. The only additional criterion was that each remote participant appeared to have a distinct subtype of PPA at the time of enrollment. The criteria for the parent treatment study included a clinical diagnosis of PPA or a related disorder, English fluency since childhood, at least 10 years of education, age of at least 40 years, and no history of other neurological or psychiatric disorders.

Subtyping was based on the international criteria (Gorno-Tempini et al., 2011). Two neurologists and one neuropsychologist independently reviewed each participant's medical history and baseline assessment results. The subtype raters also viewed videos of the participant performing language tasks, including the Cookie Theft narrative (Goodglass, Kaplan, & Barresi, 2001) and the Boston Naming Test (BNT; Kaplan, Goodglass, & Weintraub, 2001). When videos were unavailable, the raters listened to audio recordings. Disagreements between the raters were resolved through additional review of these materials and discussion between the raters. Quantitative cutoffs were not utilized.

Language and Cognitive Testing

During the evaluation sessions, participants completed a battery of language and cognitive tests, including the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975), the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005), the BNT, the 3-Picture version of the Pyramids and Palm Trees test (P&PT; Howard & Patterson, 1992), Word-Picture Matching (Rogers & Friedman, 2008), subject and object Wh-questions from the Northwestern Anagram Test (NAT; Weintraub et al., 2008), selected subtests from the Boston Diagnostic Aphasia Examination (BDAA; Goodglass et al., 2001), repetition of 5-syllable pseudowords, and the reading and spelling of irregular and regular words. The latter repetition, reading, and spelling tasks were developed at the Center for Aphasia Research and Rehabilitation. For telerehabilitation participants, a majority of the assessment battery was administered remotely. See Tables 1 through 3 for the baseline assessment results.

Telerehabilitation Participants

Participant CGR – nonfluent/agrammatic PPA—CGR participated at his home in a suburb of Washington, DC. His one-way travel time to the testing and treatment site would have been approximately 45 minutes. He enrolled in the study at the age of 48, two months after being diagnosed with nfvPPA. His naming accuracy was severely impaired at baseline, and his reading and spelling were affected by word frequency (see Table 1). The in-person nfvPPA participants had milder naming deficits, and there was little evidence of frequency or regularity effects in reading or spelling.

Participant ACR – semantic PPA—ACR participated at her home in a suburb of Washington, DC. Her one-way travel time to the testing and treatment site would have been approximately 35 minutes. She enrolled in the study at the age of 68, two years after being diagnosed with svPPA. During the baseline assessment, her advanced comprehension difficulties resulted in impaired performance on many non-semantic measures (see Table 2). Her naming accuracy was severely impaired at baseline, and her reading accuracy for low frequency irregular words was slightly lower than other word types. Due to time constraints, spelling of regular and irregular words was not assessed for most of the svPPA participants.

The in-person svPPA participants had naming impairments that were similar to ACR's, and their reading of low frequency irregular words was impaired.

Participant WCH – logopenic PPA—WCH participated at her home in a suburb of Baltimore, MD. Her one-way travel time to the testing and treatment site would have been approximately 75 minutes. She enrolled in the study at the age of 69, two months after being diagnosed with lvPPA. WCH's naming accuracy was severely impaired at baseline (see Table 3). Her reading performance was affected by word frequency. Her spelling accuracy was lower for irregular words, especially those of low frequency. All but one of the in-person lvPPA participants had BNT scores that were numerically higher than WCH's, but they were still severely impaired. There was some evidence that reading performance was lower for low frequency irregular words, compared to other word types. Spelling performance appeared to be affected by both regularity and frequency.

Telerehabilitation Platform

The equipment was delivered to the participant's home and set up before the first remote session. Each participant was provided with a Windows-based laptop computer with an internal webcam (see Figure 2). Participants were also provided with an echo-cancellation microphone/speaker (ClearOne Chat50) and an electronic signature pad for written input (SignatureGem, Topaz Systems Inc.).

A custom-developed telerehabilitation platform was utilized. VSee (www.vsee.com), a secure, Internet-based videoconferencing program, provided bidirectional audio/video communication as well as screen sharing capabilities, allowing the researcher to engage in conversation and visual interaction with the participant. Screen sharing was used with custom interactive software to display on-screen material to the participant, who was able to interact with the material by using a mouse.

Each written response that a participant made was visible on the researcher's computer screen. The image files for these responses were automatically saved and uploaded to Dropbox (www.dropbox.com). The researcher downloaded these files after each session.

Telerehabilitation Interface

There were two icons on the participant's desktop. At the scheduled time, the participant clicked on the Assessment icon or the Treatment and Practice icon, depending on the type of session. This caused the participant's laptop to log in to VSee. Next, the researcher initiated the videoconference call. Once the connection had been made, the participant clicked on the VShare button, which allowed the researcher to view and control the participant's display. The researcher then selected the appropriate assessment task, treatment script, or practice session.

If a participant had difficulty with the selection of the correct icon or the sharing of the laptop display, the researcher assumed control of the participant's laptop and completed these steps. The researcher was also able to adjust the laptop's audio and video settings.

Stimuli

For each participant, up to 120 items were selected from a set of 294 nouns. The set primarily consisted of high and low frequency words with regular orthography and high frequency words with irregular orthography, although some low frequency irregular words (e.g., *glove*) were included. For each selected item, there were three different picture exemplars. In norming conducted with unimpaired participants, these pictures have high name agreement. In the current study, oral naming accuracy for Exemplar 1 was tested twice during the baseline evaluation, and this exemplar was utilized during treatment. Oral naming accuracy for Exemplar 2 was tested once at baseline. Exemplar 2 was not utilized during treatment, but it was used to assess stimulus generalization during post-treatment testing. Exemplar 3 was only used as a foil during treatment.

Each selected item was either named correctly by the participant during all three of the baseline oral naming tests (Prophylaxis Items), or it was named incorrectly during all three of these tests (Remediation Items). All of the selected words were read and repeated accurately at baseline. The selected items were divided into three sets and were matched across sets for frequency (Baayen, Piepenbrock, & Gulikers, 1995), semantic category, and number of syllables, phonemes, and letters. Items that could not be matched were discarded.

The stimulus selection process for each remote participant is summarized in Table 4.¹ For example, CGR was able to read, repeat, and accurately name 106 items on three occasions. Ten of these items were discarded during the matching process, resulting in 32 prophylaxis items per treatment condition (untrained, phonological treatment, or orthographic treatment). His mean stimulus characteristics are presented in Supplemental Table 1. CGR's remediation candidates included 9 items that were named incorrectly on three occasions, but could be read and repeated accurately. However, these items could not be matched across sets, and the number of potential items was insufficient for analysis. Mean stimulus characteristics for ACR and WCH are presented in Supplemental Tables 2 and 3, respectively.

Procedure

Differences between in-person treatment and telerehabilitation—Other than the method of treatment delivery, the only procedural differences involved the stimulus presentation software and the practice sessions. The latter differences are described below in the Practice Sessions section. E-Prime (Psychology Software Tools) was used to present the stimuli to in-person participants. Custom software was utilized for telerehabilitation participants.

Timeline—Following the baseline evaluation, treatment took place during the next six months. In the first month of treatment, there were two sessions per week. Each session included both types of treatment. After the participant had become familiar with the treatment tasks during the first month, the practice period began. During this five-month period, shorter practice sessions occurred three times per week. One treatment session also

¹The range in the number of items per condition for in-person participants is also reported in Table 4.

occurred each month, in order to check in with the participant and verify that he or she was performing the treatment tasks correctly. In the remote version of the study, the monthly treatment sessions were retained in order to maintain consistency with the in-person version of the study. The post-treatment evaluation began one month after the end of treatment.

Baseline evaluation—The baseline evaluation occurred over the course of six sessions, with one or two sessions per week. For telerehabilitation participants, the majority of the baseline evaluation sessions were conducted via videoconferencing, but one evaluation session was conducted in person. A portion of the language and cognitive tests were administered during this session, including the MMSE, MoCA, and NAT. During the remaining sessions, each participant's language abilities were tested comprehensively, and participants were asked to name the 294 pictured nouns on three occasions. Based on the oral naming accuracy of each participant, individualized treatment words were selected as described above.

Following stimulus selection, accuracy for the selected items was also tested in two other ways: written confrontation naming and naming during scene description. In the first task, the participant was asked to print the name of each exemplar 1 picture. In the second task, the participant was asked to describe a visual scene. Each scene contained one of the selected items.

Orthographic treatment condition (OTC)—In the orthographic treatment, stimuli were presented in the following sequence: 1) Picture alone, 1.5 seconds. 2) The written word under the picture, in one of 15 fonts, 1.5 seconds. 3) The word alone, 1.5 seconds. 4) The picture-word combination (PWC) appeared again, and the participant was asked to read the word aloud. 5) A beep then signaled the participant to copy the word onto the signature pad. 6) Two recognition slides were presented in succession, with the words “Did you see this?” and either the correct PWC or a foil. Instructions specified that both the identical exemplar of the picture and the word in the identical font had to be present for a “Yes” response. The participant responded by saying “Yes” or “No.” The foil used for each PWC was one of the following: 1) The correct picture paired with the written word in a second, incorrect font; 2) An incorrect exemplar of the picture paired with the correct font; or 3) The incorrect exemplar of the picture with the second, incorrect font. To perform this task correctly, visual aspects of both the picture and the word must be encoded (i.e., this task cannot be done verbally). The purpose of this task is to ensure that the participant is focusing on both the picture and the written word.

Phonological treatment condition (PTC)—This treatment was similar in design to the OTC. However, the picture was not accompanied by its written name. Rather, it was accompanied by a string of symbols (e.g., #\$\$\$) in a specific font. The symbol string, though unrelated to the picture, was included in this condition so that the participant would perform the same task as in the OTC, thereby keeping the conditions well matched for activity and engagement. The participant was asked to look at the picture and string of symbols on the screen as the pre-recorded name was presented auditorily, and then to repeat the name.

The participant was then given a yes/no recognition task analogous to the one given in the OTC: the task and foil options were the same, the symbols appeared in one of 15 distinctive fonts, and the participant was asked to remember both the symbols and the picture. The symbols themselves, like the words in the OTC, did not change in the foils; only the font was changed.

Spaced retrieval learning—A spaced retrieval paradigm was incorporated into the design at the stage of the recognition slides (#6 above) to increase the likelihood of long-term retention (e.g., Fridriksson, Holland, Beeson, & Morrow, 2005). First, in level 1, each PWC or picture-symbol combination (PSC) was presented alone, followed immediately by the yes-no recognition test. If a recognition accuracy of 90% was reached in both treatments, then the participant advanced to level 2, in which the number of events (trials or tests) between the PWC or PSC and its recognition test was increased by one. Here, the participant was presented with two PWC or PSC trials in a row, and then their recognition tests were presented in the same order. Similarly, if the participant reached 90% accuracy on level 2, then he or she advanced to level 4, in which four trials were followed by four recognition tests.

Practice sessions—These sessions were similar to the treatment sessions, except that the recognition tests were omitted. In the OTC, a slide with the pictured item was presented to the telerehabilitation participants, and it was followed by a slide with the picture and the corresponding written word. The telerehabilitation participant read the word out loud and then transcribed the word on the signature pad. In the PTC, a slide with the pictured item was presented, and it was followed by a slide with the picture and a symbol string. The telerehabilitation participant then heard the name of the picture and repeated it.

Similarly, for the in-person treatment, each participant used training cards to perform these tasks with a caregiver three times per week. Each card in the OTC had one picture on the front. The back of the card had the same picture with the corresponding written word. The participant looked at the picture on the front, turned the card over, read aloud the name of the picture, and then transcribed the name on a response sheet.

Each card in the PTC had one picture on the front, while the back had the same picture with the associated symbol string. The participant looked at the picture on the front, and then looked at the picture and symbols on the back. The caregiver then spoke the name of the picture, which the participant repeated.

The caregiver also ensured that the participant practiced the two sets appropriately and kept a practice session log. The experimenters collected the cards and session log at the end of the six-month treatment period.

Post-treatment evaluation—Post-treatment testing began one month after the end of treatment. During this evaluation, treatment effects were measured, and the language and cognitive battery was re-administered. No testing was conducted between the baseline and post-treatment evaluations.

Data analysis—Naming accuracy was analyzed separately for prophylaxis and remediation items, and a participant's data for each type of item were included in the analyses when there were at least 10 items per condition. All analyses were two-tailed.

The remote participants' individual data were analyzed in two ways.² In the first set of analyses, the binomial test was utilized to compare pre-treatment and post-treatment accuracy within each condition. In the second set of analyses, the chi-square test was used to compare post-treatment naming accuracy within each treatment condition to post-treatment accuracy within the untrained condition. When the minimum expected cell count was less than five, Fisher's exact test was utilized instead of the chi-square test.

In another set of analyses, the effects of telerehabilitation on oral naming accuracy were compared to those of in-person treatment. For each participant, the change in naming accuracy (CNA) from baseline to post-treatment was calculated for each type of item (prophylaxis or remediation) within each condition. Next, treatment effects were estimated for each treatment condition by calculating the difference in the size of the CNA between untrained and treated items. To determine if the treatment effects for each telerehabilitation participant were significantly different from the effects that were observed for in-person participants with the same subtype, we utilized a modified *t* test that was designed to compare a participant's score to a small normative sample (see Crawford & Howell, 1998; Sokal & Rohlf, 1995).

Results

Telerehabilitation

Participant CGR – nonfluent/agrammatic PPA—CGR was able to initiate VSee and share his computer screen without assistance from the experimenter. CGR's naming accuracy for prophylaxis items is presented in Table 5.

For both exemplars, CGR's post-treatment oral naming accuracy showed a significant decrease in the UC. In the OTC, there was a marginally significant decline for Exemplar 1 ($p = .063$). There were no other significant or marginally significant changes in either treatment condition. Compared to UC, post-treatment accuracy for Exemplar 1 was significantly greater in both PTC and OTC, but accuracy for Exemplar 2 was not significantly greater in either treatment condition.

For written naming, there were no significant changes within any condition or significant differences between conditions. For the scene description task, accuracy for the target items increased significantly within the PTC, but not within UC or OTC. There were no significant differences between conditions.

Participant ACR – semantic PPA—During the study, ACR frequently required assistance from the experimenter to initiate VSee and share her computer screen. ACR's naming accuracy for prophylaxis and remediation items is presented in Table 6.

²Due to differences in the number of items per condition, for ACR statistical power for single-subject analyses was greater for remediation items, and for WCH statistical power for single-subject analyses was greater for prophylaxis items.

For prophylaxis items, ACR's post-treatment accuracy did not show a significant decline within any condition, for any task. Furthermore, there were no significant differences between UC and the treatment conditions.

For remediation items, ACR's oral naming accuracy in the PTC increased significantly for Exemplar 1 and increased marginally for Exemplar 2 ($p = .063$). There were no significant changes within other conditions or for other tasks. Compared to UC, post-treatment oral naming accuracy in PTC was significantly greater for Exemplar 1 and marginally greater for Exemplar 2 ($p = .052$). There were no significant differences between UC and OTC, and there were no significant differences within the other tasks.

Participant WCH – logopenic PPA—WCH was typically able to initiate VSee and share her computer screen without assistance. WCH's naming accuracy for prophylaxis and remediation items is presented in Table 7.

For prophylaxis items, WCH's oral naming accuracy in UC showed a significant decline for both exemplars. In OTC, there was a marginally significant decline for Exemplar 2 ($p = .063$). There were no other significant or marginally significant changes in either treatment condition or for any other task. Compared to UC, post-treatment oral naming accuracy in PTC was significantly greater for Exemplar 1 and marginally greater for Exemplar 2 ($p = .061$). In OTC, post-treatment oral naming accuracy for Exemplar 1 and post-treatment written naming accuracy were significantly greater compared to UC. For remediation items, WCH's naming accuracy did not show a significant increase in any condition or within any task.

Summary—All subjects exhibited positive treatment effects. For prophylaxis items, CGR and WCH showed maintenance of naming for at least one exemplar in both treatment conditions. Furthermore, CGR's naming of target items from the PTC increased within the scene description task, and WCH's post-treatment written naming accuracy was significantly greater in OTC, compared to UC. ACR's naming of remediation items increased in the PTC.

Comparison of Telerehabilitation and In-Person Treatment

The results of these comparisons are presented in Table 8. In Figures 3 through 7, the treatment effect is plotted in percentage points for each condition.

CGR/nfvPPA—The nvPPA data for prophylaxis items are plotted in Figure 3. For both treatments and both exemplars, CGR had treatment effects that were significantly larger than the treatment effects for in-person nvPPA participants. None of the in-person nvPPA participants had remediation items.

ACR/svPPA—The svPPA data for prophylaxis and remediation items are plotted in Figures 4 and 5, respectively. All of ACR's treatment effects were within the expected range for individuals with svPPA, and there were no significant or marginally significant differences between her treatment effects and those of the in-person participants.

WCH/lvPPA—The lvPPA data for prophylaxis and remediation items are plotted in Figures 6 and 7, respectively. For prophylaxis items, WCH's treatment effects for both exemplars in the PTC and for Exemplar 1 in the OTC were marginally greater than the average effects for in-person lvPPA participants. For remediation items, WCH's treatment effect for Exemplar 2 in the OTC was marginally smaller than the average effect for in-person lvPPA participants. There were no other significant or marginally significant differences between her treatment effects and those of the in-person lvPPA participants.

Summary—The three telerehabilitation participants typically showed effects that were either within the expected range or larger than expected.

Discussion

The goal of the current study was to evaluate the feasibility and efficacy of a telerehabilitation-based approach to anomia treatment in PPA. Each of the telerehabilitation participants represented a distinct subtype of PPA. Following a baseline evaluation of language and cognition, a phonological treatment (PTC) and an orthographic treatment (OTC) were administered remotely to the three participants over the course of six months. One month after the end of treatment, naming accuracy was measured for the treated items and the matched untrained items (UC).

Compared to UC, all three participants exhibited positive treatment effects. For prophylaxis items, CGR and WCH showed significantly greater oral naming accuracy for Exemplar 1 in both treatment conditions. These findings are consistent with the prediction that both treatments would be effective in nfvPPA and lvPPA. In addition, WCH demonstrated greater written naming accuracy for prophylaxis items in OTC, which is consistent with previous findings (Meyer et al., 2015). For remediation items, ACR's oral naming accuracy for Exemplar 1 was significantly greater in PTC. Unexpectedly, ACR did not show significant treatment effects in OTC. This finding is inconsistent with the prediction that the orthographic treatment would be more effective in svPPA.

All three participants also exhibited evidence of stimulus generalization or generalization to other tasks. Compared to UC, ACR showed marginally greater accuracy for Exemplar 2 remediation items in PTC, and WCH demonstrated marginally greater accuracy for Exemplar 2 prophylaxis items in PTC. In the scene description task, CGR's naming of target items showed a significant increase in PTC.

There was little evidence that either treatment generalized to untreated items. In UC, WCH's accuracy for remediation items increased numerically within several tasks, but these changes were not statistically significant. Similarly, CGR's accuracy for untrained items increased within the scene description task, but this change was not significant.

A number of studies have examined generalization in svPPA, and anomia treatment effects do not typically generalize to untreated items or different tasks (see Jokel et al., 2014; cf. Henry, Rising, et al., 2013). Similar to the current study, generalization to alternative exemplars of trained items has been observed in svPPA (Green Heredia, Sage, Lambon Ralph, & Berthier, 2009; Jokel et al., 2010). A smaller number of studies have examined

generalization of anomia treatment effects in nvfPPA and lvPPA, and generalization has been found in both subtypes. For example, Jokel et al. (2009) observed improvement in syntactic production skills in nvfPPA. In lvPPA, Meyer et al. (2015) found cross-language transfer within confrontation naming and naming to definition tasks, while other studies have found generalization to untreated items (Beeson et al., 2011; Henry, Rising, et al., 2013; Newhart et al., 2009).

Compared to in-person participants with the same subtype of PPA, each of the telerehabilitation participants typically showed effects that were either within the expected range or larger than expected. CGR's treatment effects for prophylaxis items were larger than those observed for in-person nvfPPA participants. It remains unclear if this pattern is due to greater efficacy for telerehabilitation among participants with nvfPPA, or if it is simply due to CGR's larger decline in general naming accuracy.³ A large decline in general naming ability can amplify the effects of prophylaxis treatment.

For both prophylaxis items and remediation items, ACR's treatment effects were within the expected range for participants with svPPA. For prophylaxis items, WCH's treatment effects were either larger than expected or within the expected range for individuals with lvPPA. For remediation items, her treatment effects were either within the expected range or smaller than expected for those with lvPPA. Similar to the pattern that was observed for CGR, these differences may be due to a larger decline in general naming accuracy for WCH compared to the in-person lvPPA participants.

In order to establish the generalizability of the current study's findings, it will be necessary to collect remote treatment data from a larger sample of PPA participants in the future. Although the number of remote participants in the current study is small, the results provide evidence that a telerehabilitation-based approach to language treatment is feasible in PPA, and it suggests that remote anomia treatment can be effective in all three subtypes of PPA.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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³See Supplemental Table 4 for the in-person participants' post-treatment naming accuracy for Exemplar 1 prophylaxis items in UC.

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Figure 1.

The blue ovals depict internal representations, while the red rectangles depict external stimuli and outputs. Bold arrows identify the stimuli that were paired during treatment, blue arrows represent the pathways that are normally activated during confrontation naming, red arrows represent additional pathways that were activated during treatment, and shaded blue ovals depict the representations that are thought to be strengthened by treatment.

Figure 2.
Telerehabilitation participant's computer (top) and example treatment display (bottom).

Figure 3.

Treatment effect in percentage points for prophylaxis items, nfvPPA participants. For this figure and those that follow, the participants are ordered based on their average treatment effect for Exemplar 1.

Figure 4.
Treatment effect in percentage points for prophylaxis items, svPPA participants.

Figure 5.
Treatment effect in percentage points for remediation items, svPPA participants.

Figure 6.

Treatment effect in percentage points for prophylaxis items, lvPPA participants.

Figure 7.

Treatment effect in percentage points for remediation items, lvPPA participants.

Table 1
Demographic Information and Baseline Assessment Results for Participants with nvPPA

	Remote		In-Person			
	CGR	NFV1	NFV2	NFV3	NFV4	M(SD)
Age at Baseline	48	55	67	75	74	67.8 (9.2)
Education (years)	12	16	15	18	18	16.8 (1.5)
Sex	M	M	M	M	M	
MMSE/30	24	29	26	27	29	27.8 (1.5)
MoCA/30	17	24	27	19	26	24 (3.6)
Boston Naming Test/60	24	54	57	51	44	51.5 (5.6)
P&PT, 3 Pictures/52	48	48	50	51	49	49.5 (1.3)
Word-Picture Matching/48	48	48	48	47	48	47.8 (0.5)
Northwestern Anagram Test/10	3	5	8	0	9	5.5 (4.0)
BDAE Articulatory Agility/7	2	4	6	6	7	5.8 (1.3)
BDAE Phrase Length/7	2	7	7	7	6	6.8 (0.5)
BDAE Embedded Sentences/10	9	10	10	7	10	9.3 (1.5)
BDAE Sentence Repetition/10	1	8	9	8	9	8.5 (0.6)
Pseudoword Repetition/10	0	9	8	6	10	8.3 (1.7)
Reading HF Irregular Words/10	9	8	10	9	10	9.3 (1.0)
Reading LF Irregular Words/10	7	10	10	10	9	9.8 (0.5)
Reading HF Regular Words	8	10	10	10	10	10 (0)
Reading LF Regular Words/10	5	9	10	10	10	9.8 (0.5)
Spelling HF Irregular Words/10	8	9	10	NA	10	9.7 (0.6)
Spelling LF Irregular Words/10	5	8	10	NA	8	8.7 (1.2)
Spelling HF Regular Words/10	9	10	10	NA	10	10 (0)
Spelling LF Regular Words/10	3	7	10	NA	9	8.7 (1.5)

Note. MMSE = Mini-Mental State Examination, MoCA = Montreal Cognitive Assessment, P&PT = Pyramids and Palm Trees, BDAE = Boston Diagnostic Aphasia Examination, HF = high frequency, LF = low frequency, NA = not administered.

Table 2
Demographic Information and Baseline Assessment Results for Participants with svPPA

	Remote		In-Person				
	ACR	SV1	SV2	SV3	M	SD	
Age at Baseline	68	71	61	59	63.7	(6.4)	
Education (years)	16	20	16	18	18	(2)	
Sex	F	M	M	F			
MMSE/30	12	27	26	NA	26.5	(0.7)	
MoCA/30	1	20	19	12	17	(4.4)	
Boston Naming Test/60	10	14	11	6	10.3	(4.0)	
P&PT, 3 Pictures/52	22	38	45	17	33.3	(14.6)	
Word-Picture Matching/48	39	43	43	15	33.7	(16.2)	
Northwestern Anagram Test /10	0	4	9	6	6.3	(2.5)	
BDAE Articulatory Agility/7	7	7	7	7	7	(0)	
BDAE Phrase Length/7	6	7	7	7	7	(0)	
BDAE Embedded Sentences/10	1	9	10	4	7.7	(3.2)	
BDAE Sentence Repetition/10	3	10	10	2	7.3	(4.6)	
Pseudoword Repetition/10	4	4	10	6	6.7	(3.1)	
Reading HF Irregular Words/10	9	10	10	6	8.7	(2.3)	
Reading LF Irregular Words/10	7	7	6	1	4.7	(3.2)	
Reading HF Regular Words/10	8	10	10	9	9.7	(0.6)	
Reading LF Regular Words/10	9	10	10	9	9.7	(0.6)	
Spelling HF Irregular Words/10	NA	NA	7	NA			
Spelling LF Irregular Words/10	NA	NA	1	NA			
Spelling HF Regular Words/10	NA	NA	8	NA			
Spelling LF Regular Words/10	NA	NA	8	NA			

Note. MMSE = Mini-Mental State Examination, MoCA = Montreal Cognitive Assessment, P&PT = Pyramids and Palm Trees, BDAE = Boston Diagnostic Aphasia Examination, HF = high frequency, LF = low frequency, NA = not administered.

Table 3

Demographic Information and Baseline Assessment Results for Participants with IvPPA

	Remote		In-Person						
	WCH	LV1	LV2	LV3	LV4	LV5	LV6	LV7	M (SD)
Age at Baseline	69	66	71	88	73	68	67	67	71.4 (7.7)
Education (years)	18	18	18	16	18	18	14	18	17.1 (1.6)
Sex	F	F	F	M	F	M	F	F	
MMSE/30	18	27	21	18	25	27	19	27	23.4 (4.0)
MoCA/30	12	20	16	5	21	18	12	20	16 (5.7)
Boston Naming Test/60	15	46	18	33	31	34	14	37	30.4 (11.0)
P&PT, 3 Pictures/52	49	51	40	35	50	51	48	49	46.3 (6.3)
Word-Picture Matching/48	44	48	43	45	48	48	47	48	46.7 (2.0)
Northwestern Anagram Test/10	6	9	9	5	7	5	7	5	6.7 (1.8)
BDAE Articulatory Agility/7	7	7	7	5	7	7	6	6	6.4 (0.8)
BDAE Phrase Length/7	7	7	7	7	7	7	7	7	7 (0)
BDAE Embedded Sentences/10	4	10	10	7	10	6	3	5	7.3 (2.8)
BDAE Sentence Repetition/10	3	7	8	4	6	7	2	4	5.4 (2.1)
Pseudoword Repetition/10	7	9	NA	9	NA	0	0	8	5.2 (4.8)
Reading HF Irregular Words/10	10	NA	10	10	10	10	8	10	9.7 (0.8)
Reading LF Irregular Words/10	8	NA	9	10	8	9	6	5	7.8 (1.9)
Reading HF Regular Words/10	10	NA	10	10	10	10	10	10	10 (0)
Reading LF Regular Words/10	8	NA	10	10	10	10	10	10	10 (0)
Spelling HF Irregular Words/10	7	NA	7	7	10	8	NA	10	8.4 (1.5)
Spelling LF Irregular Words/10	2	NA	4	5	10	8	NA	9	7.2 (2.6)
Spelling HF Regular Words/10	10	NA	10	9	10	10	NA	10	9.8 (0.4)
Spelling LF Regular Words/10	9	NA	9	8	10	6	NA	9	8.4 (1.5)

Note. MMSE = Mini-Mental State Examination, MoCA = Montreal Cognitive Assessment, P&PT = Pyramids and Palm Trees, BDAE = Boston Diagnostic Aphasia Examination, HF = high frequency, LF = low frequency, NA = not administered.

Table 4

Stimulus Selection

	Prophylaxis				Remediation			
	<u>Candidates</u>	<u>Discarded</u>	<u>Items per Condition</u>	<u>Range for IP</u>	<u>Candidates</u>	<u>Discarded</u>	<u>Items per Condition</u>	<u>Range for IP</u>
CGR	106	10	32	40	9	9	0	NA
ACR	36	6	10	12–19	98	8	30	21–31
WCH	102	24	26	18–40	45	3	14	11–20

Note. IP = In-Person Participants, NA = Not Applicable.

Number of Items Named Correctly, CGR

Prophylaxis											
UC				PTC		OTC		Pre-Treatment		Post-Treatment	
	Pre	Post	Pre vs. Post	Pre	Post	Pre vs. Post	Pre	Post	Pre vs. Post	UC vs. PTC	UC vs. OTC
Ex. 1	32	19	$p < .001$	32	29	$p = .250$	32	27	$p = .063$	NA	NA
Ex. 2	32	25	$p = .016$	32	30	$p = .500$	32	28	$p = .125$	NA	NA
Writing	26	26	NA	24	25	$p = 1$	27	29	$p = .625$	$p = .545$	$p = .740$
Scenes	24	27	$p = .180$	20	28	$p = .039$	23	28	$p = .180$	$p = .599$	$p = .784$
										$p = 1^f$	$p = 1^f$

Note. p -values for the pre vs. post comparisons are from the binomial test. p -values for the pre-treatment and post-treatment comparisons are from the chi-square test or Fisher's exact test (superscript f). UC = Untrained Condition, PTC = Phonological Treatment Condition, OTC = Orthographic Treatment Condition, Ex. 1 = Exemplar 1, Ex. 2 = Exemplar 2, NA = not applicable.

Table 6

Number of Items Named Correctly, ACR

Prophylaxis													
UC				PTC				OTC				Pre-Treatment	
Pre	Post	Pre vs. Post		Pre	Post	Pre vs. Post		Pre	Post	Pre vs. Post		UC vs. PTC	UC vs. OTC
Ex. 1													
10	8	$p = .500$		10	10	NA		10	9	$p = 1$		NA	$p = .474^f$
Ex. 2													
10	7	$p = .250$		10	9	$p = 1$		10	9	$p = 1$		NA	$p = .582^f$
Writing													
5	2	$p = .250$		5	3	$p = .500$		5	4	$p = 1$		NA	$p = .628^f$
Scenes													
6	3	$p = .250$		6	4	$p = .500$		5	6	$p = 1$		NA	$p = .370^f$
Remediation													
UC				PTC				OTC				Pre-Treatment	
Pre	Post	Pre vs. Post		Pre	Post	Pre vs. Post		Pre	Post	Pre vs. Post		UC vs. PTC	UC vs. OTC
Ex. 1													
0	0	NA		0	7	$p = .016$		0	4	$p = .125$		NA	$p = .112^f$
Ex. 2													
0	0	NA		0	5	$p = .063$		0	4	$p = .125$		NA	$p = .112^f$
Writing													
1	0	$p = 1$		0	1	$p = 1$		1	0	$p = 1$		NA	NA
Scenes													
5	2	$p = .250$		6	6	NA		2	3	$p = 1$		$p = .739$	$p = .254^f$

Note. p -values for the pre vs. post comparisons are from the binomial test. p -values for the pre-treatment and post-treatment comparisons are from the chi-square test or Fisher's exact test (superscript f). UC = Untrained Condition, PTC = Phonological Treatment Condition, OTC = Orthographic Treatment Condition, Ex. 1 = Exemplar 1, Ex. 2 = Exemplar 2, NA = not applicable.

Table 7

Number of Items Named Correctly, WCH

Prophylaxis															
UC				PTC				OTC				Pre-Treatment		Post-Treatment	
	Pre	Post	Pre vs. Post	Pre	Post	Pre vs. Post		Pre	Post	Pre vs. Post	UC vs. PTC	UC vs. OTC	UC vs. PTC	UC vs. OTC	
Ex. 1	26	17	$p = .004$	26	23	$p = .250$		26	24	$p = .500$	NA	NA	$p = .048$	$p = .017$	
Ex. 2	26	16	$p = .002$	26	22	$p = .125$		26	21	$p = .063$	NA	NA	$p = .061$	$p = .126$	
Writing	15	12	$p = .375$	17	15	$p = .754$		14	19	$p = .125$	$p = .569$	$p = .780$	$p = .405$	$p = .048$	
Scenes	18	14	$p = .289$	18	18	NA		18	16	$p = .625$	NA	NA	$p = .254$	$p = .575$	
Remediation															
UC				PTC				OTC				Pre-Treatment		Post-Treatment	
	Pre	Post	Pre vs. Post	Pre	Post	Pre vs. Post		Pre	Post	Pre vs. Post	UC vs. PTC	UC vs. OTC	UC vs. PTC	UC vs. OTC	
Ex. 1	0	2	$p = .500$	0	4	$p = .125$		0	1	$p = 1$	NA	NA	$p = .648^f$	$p = 1^f$	
Ex. 2	0	2	$p = .500$	0	2	$p = .500$		0	1	$p = 1$	NA	NA	$p = 1^f$	$p = 1^f$	
Writing	2	0	$p = .500$	1	2	$p = 1$		2	1	$p = 1$	$p = 1^f$	NA	$p = .481^f$	$p = 1^f$	
Scenes	2	3	$p = 1$	3	3	NA		4	3	$p = 1$	$p = 1^f$	$p = .648^f$	NA	NA	

Note. p -values for the pre vs. post comparisons are from the binomial test. p -values for the pre-treatment and post-treatment comparisons are from the chi-square test or Fisher's exact test (superscript f). UC = Untrained Condition, PTC = Phonological Treatment Condition, OTC = Orthographic Treatment Condition, Ex. 1 = Exemplar 1, Ex. 2 = Exemplar 2, NA = not applicable.

Table 8

Comparison of Treatment Effects

Treatment	Prophylaxis			Remediation							
	Exemplar 1	Exemplar 2		Exemplar 1	Exemplar 2						
	df	t	p	df	t	p					
CGR vs. In-Person nfvPPA Participants											
Phonological	3	7.01	<.01	3	6.85	<.01	NA	NA	NA	NA	
Orthographic	3	6.97	<.01	3	6.26	<.01	NA	NA	NA	NA	
ACR vs. In-Person svPPA Participants											
Phonological	df	t	p	df	t	p	df	t	p		
	1	0.18	ns	1	-1.62	ns	2	-0.29	ns	2	-1.31
Orthographic	df	t	p	df	t	p	df	t	p		
	1	-1.30	ns	1	-0.18	ns	2	-1.14	ns	2	-0.93
WCH vs. In-Person lvPPA Participants											
Phonological	df	t	p	df	t	p	df	t	p		
	6	2.45	=.05	6	2.28	<.10	2	-0.78	ns	2	-1.51
Orthographic	df	t	p	df	t	p	df	t	p		
	6	2.10	<.10	6	0.96	ns	2	-1.70	ns	2	-3.33

Note. NA = not applicable, ns = not significant.