



Development of an Impairment-Based Individualized Treatment Workflow Using an iPad-Based Software Platform

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ABSTRACT

Individuals with language and cognitive deficits following brain damage likely require long-term rehabilitation. Consequently, it is a huge practical problem to provide the continued communication therapy that these individuals require. The present project describes the development of an impairment-based individualized treatment workflow using a software platform called Constant Therapy. This article is organized into two sections. We will first describe the general methods of the treatment workflow for patients involved in this study. There are four steps in this process: (1) the patient's impairment is assessed using standardized tests, (2) the patient is assigned a specific and individualized treatment plan, (3) the patient practices the therapy at home and at the clinic, and (4) the clinician and the patient can analyze the results of the patient's performance remotely and monitor and alter the treatment plan accordingly. The second section provides four case studies that provide a representative sample of participants progressing through their individualized treatment plan. The preliminary results of the patient treatment provide encouraging evidence for the feasibility of a rehabilitation program for individuals with brain damage based on the iPad (Apple Inc., Cupertino, CA).

KEYWORDS: iPad, constant therapy, individualized, rehabilitation

Learning Outcomes: As a result of this activity, the reader will be able to describe the various cognitive/language operations involved in specific evidenced-based therapies, and explain the merits/disadvantages of targeted impairment-based rehabilitation for patients with language and cognitive deficits.

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About 795,000 Americans each year suffer a new or recurrent stroke.¹ Also, ~1.7 million individuals suffer from traumatic brain injury each year.² Individuals with language and cognitive deficits following brain damage likely require long-term rehabilitation. Consequently, it is a huge practical problem to provide the continued communication therapy that these individuals require.

USING TECHNOLOGY TO IMPROVE TREATMENT DELIVERY

There has been tremendous recent attention in research regarding the use and applicability of technology to improve treatment delivery. These range from implementing remote treatment delivery options to facilitate the provision of rehabilitation to individuals who cannot travel to obtain rehabilitation services to brain training software that individuals can use and interact with on a daily basis. Speech-language pathology rehabilitation, especially aphasia rehabilitation, is particularly suited for remote/telerehabilitation due to the emphasis on speech/visual and auditory communication. Recent studies have examined the efficacy of rehabilitation techniques such as videoconferencing for individuals with hearing, stuttering, and motor speech issues.^{3,4} Other studies have provided aphasia therapy over the Internet to individual patients.^{5,6} In a recent review, Van de Sandt-Koenderman identified the role of technology in the different domains of the International Classification of Functioning, Disability, and Health code that include alleviating impairment, facilitating functional communication, and social participation.⁷ She posits that technology will reshape the way clinicians are engaged in their patient's rehabilitation. Therefore, not only is there an increased awareness and momentum for applying computer technology in the rehabilitation of aphasia, there is increased patient demand to transition from traditional but outdated flash card-based therapy to keep up with the evolution of technology.

WHAT IS THE EVIDENCE BEHIND USING TECHNOLOGY TO DELIVER TREATMENT?

There have been several efforts to apply various forms of computer technology to rehabilitation of

brain-injured patients. Given the focus of this special issue, we will limit our review of the evidence on the application of technology (available via Internet connection either on a computer or mobile application) for rehabilitation to language and communication deficits in the spirit of retraining disordered function, and hence we will refrain from discussion about alternative/augmentative technologies (and text-to-speech devices) that serve as communication aids. These include programs such as Lingraphica (Lingraphica Inc., Princeton, NJ) Sentence-Shaper (Psycholinguistic Technologies, Jenkintown, PA) and Touchspeak (Touchspeak™, London, England). Internet-based software treatments have been increasingly available for individuals with brain damage. For instance, a few studies have examined the effectiveness of CogMed (Pearson Company, Scandinavia, Sweden), a software targeted at improving working memory abilities in individuals with brain injury.^{8,9} These studies found improvements in working memory skills on the trained CogMed software as well as on other working memory tasks and functional settings. Likewise, Barnes et al examined the effectiveness of the software Posit Science (Posit Science, San Francisco, CA) in improving auditory processing speed in individuals with mild cognitive impairment (MCI).¹⁰ Although differences between the experimental and control groups were not statistically significant, verbal learning, and memory measures were higher in the experimental group than the control group. In another study, also examining cognitive training in MCI, Finn and McDonald used Lumosity software (Lumos Lab, San Francisco, CA) to target attention, processing speed, visual memory in experimental and wait-listed controls.¹¹ Results showed experimental participants improved on the training exercises more than the controls. Software solutions such as Lumosity and Posit Science provide a wide range of primarily cognitive therapy tasks that include attention, memory, and visuospatial processing, but they are not necessarily targeted toward individuals with brain damage. They appear to be geared more toward healthy older adults interested in delaying age-related cognitive decline. It should also be pointed out that these software platforms are primarily delivered on a computer (PC/MAC) over the Internet and are not specifically tablet-based delivery systems.

There are other software solutions targeted specifically at aphasia therapy. Notwithstanding communication aids such as Sentence Shaper and Lingraphica, recent studies have demonstrated that use of “virtual speech therapists” in delivering remote language therapy to replace face-to-face patient-clinician sessions. Thus, Sentactics¹² (Sentactics Corporation, Concord, CA) provides therapy for sentence production deficits and Oral Reading for Language in Aphasia with Virtual Therapist (ORLA-VT)¹³ provides oral reading practice for patients with aphasia. These technology-based rehabilitation solutions are limited in their functionality and range of available therapy tasks but provide a promising alternative to traditional flash card-based therapy.

INDIVIDUALIZING REHABILITATION OPTIONS FOR PATIENTS

A relatively unanswered question in most of the broad software platforms that are currently available is the nature and specificity of treatment provided. Given that all these software platforms can be used with non-brain-damaged individuals and brain-damaged individuals, is the treatment targeting a specific impairment that the patient exhibits or is it primarily a brain exercise? For both the software-based platforms and the virtual-therapist platforms, can therapy be individualized based on the patients’ demographic profile and level of impairment severity? What are the pretreatment profiles of participants enrolled in treatment? How does performance improve, stabilize, or plateau as a function of this training? These issues are all very difficult to address as no two patients are alike in their demographic profile and, more importantly, no two patients are alike in their treatment outcomes. Nonetheless, the burden of evidence for technology-based treatment applications is no different than traditional treatment approach for rehabilitation after brain damage. Until we begin to address these questions, it is difficult to recommend technology-based applications for rehabilitation as replacements for traditional flash card-based therapy to improve clinical care for patients with brain damage.

In this article, we describe the development of an impairment-based, individualized treatment plan for patients that can be delivered through an iPad (Apple Inc., Cupertino, CA) software platform. Because of the flexibility that iPads provide to patients and the accessibility to free/paid apps that provide variable levels of exercises, it is important to standardize the nature and form of treatment that is provided to patients using iPads. Second, because patients have access to iPads at home, it provides a unique opportunity to examine the extent of compliance when patients are provided with a homework regimen, something that is very difficult to assess when providing traditional paper-and-pencil homework tasks. This article describes a portion of a broader project examining the effectiveness of specific impairment-based treatments for patients with brain damage in which a large group ($n = 55$) patients entered into a prospective clinical efficacy study.

This article is organized into two sections. We will first describe the general methods of the treatment workflow for patients involved in this study. The second section provides four case studies that provide a representative sample of participants progressing through their individualized treatment plan. Because the therapy is delivered on an iPad, patients can either practice the therapy tasks assigned to them in the clinic or at home on a regular basis. Patient performance (both accuracy and latency) is analyzed on a periodic basis and patients progress to the next level of hierarchy after a certain level of performance criteria is met.

METHODS

Treatment Workflow

In this section, we describe the treatment workflow for each individual patient participating in our ongoing clinical efficacy study.

ASSESSMENT OF PATIENT IMPAIRMENT

Each patient is given a battery of standardized language tests, including the Revised-Western Aphasia Battery (R-WAB)¹⁴ to establish the type and severity of aphasia, the Boston Naming Test (BNT)¹⁵ to determine confrontation naming ability, the Pyramids and Palm Trees¹⁶

to determine overall soundness of the semantic system, and the Cognitive Linguistic Quick Test (CLQT)¹⁷ to determine the relative contribution of cognitive deficits such as attention and memory to language dysfunction and to rule out dementia. Based on the performance on each of these tests, a general profile is built for each patient based on whether they present with primary language deficits or primary cognitive deficits, and within each category, whether they present with low performance in that domain (more than half test scores in that domain are below 50%) or high performance (more than half test scores in that domain are above 50%). Clearly, patients present with a continuum of language/cognitive deficits, and therefore, generally, WAB Language Quotient (LQ), Aphasia Quotient (AQ), BNT, and Pyramids and Palm Trees (PPTT) tests are used to evaluate language skills and WAB Cortical Quotient (CQ) and Cognitive Linguistic Quick Test (CLQT) is used to evaluate cognitive skills. Performance on these tasks serve as a starting point for the therapy assignment; for instance, if a patient's letter discrimination score is 40% on WAB, this patient would likely benefit from working on sound-to-letter matching exercises.

ASSIGN INDIVIDUALIZED TASKS FOR EACH PATIENT

The next step in the treatment workflow is to assign specific therapy tasks for each patient based on their relative language and cognitive profile. We implemented the Constant Therapy iOS platform (www.constanttherapy.com) to deliver the therapy. The choice of therapy tasks to be assigned came from a set of 30+ therapy tasks broadly divided in language and cognitive therapy. Language therapy tasks were divided into (1) naming therapy: (a) rhyme judgment, (b) syllable identification, (c) phoneme-sound identification, (d) category matching, (e) feature matching, and (f) picture naming; (2) reading therapy: (a) spoken word-to-written word identification, (b) written word category identification, (c) reading passages, (d) long passage reading comprehension, and (e) reading maps, (3) writing therapy: (a) word copy completion, (b) word copy, (c) word spelling completion, (d) word spelling, (e) picture spelling completion, (f) picture spelling, (g) sound-to-letter match-

ing, and (h) letter-to-sound matching; (4) sentence planning: (a) active sentence completion, (b) passive sentence completion. In addition, cognitive therapy tasks were divided into (1) visuospatial processing: (a) symbol cancellation, (b) telling time/analog clock; (2) memory: (a) visuospatial picture/word memory matching, (b) visuospatial auditory memory, and (c) voicemail task; (3) attention: (a) response inhibition, (b) symbol cancellation; (4) problem solving: (a) analytical reasoning with subtasks such as (i) alphabetical word ordering, (ii) alphabetical picture ordering; (b) arithmetic with subtasks such as (i) addition, (ii) multiplication, (iii) subtraction, and (iv) division; and (c) quantitative reasoning with subtasks such as (i) time estimation task, (ii) word math problems; (5) executive function: (a) sequencing a set of steps/instructions. Details regarding the development of the stimuli for each of these tasks are not provided here due to space limitations. The range of therapy tasks, their scientific and clinical rationale, and specific evidence regarding their efficacy are provided in Appendix 1.

The general procedures for assignment of treatment were as follows. During the initial session, a subset of potential therapy tasks was assigned as baselines. As long as performance on a task was below 80% accuracy, that task was assigned for therapy. Because we examined both accuracy and latency as our dependent measures, we chose 80% accuracy as a cutoff to allow for examination of a maximum of 20% change in accuracy and corresponding decreases in latencies. If a patient performed higher than 80% on a particular task, the next level of difficulty of that task was assigned to the patient, or a different task examining the same skill (e.g., rhyming instead of sound identification) was assigned to the patient. For each patient, five to six tasks with up to 10 items in each task were assigned as that week's "therapy schedule." Participants were incrementally assigned tasks during the course of the 10-week treatment program. Therefore, each patient was provided with an individualized treatment plan, which was modified frequently during the course of their participation in the study.

Participant Action at Home/Clinic Participants were provided with usernames and passwords to log into the Constant Therapy app and

were then asked to practice the therapy up to 6 days a week for 1 hour each week. Participants were assured that there was no penalty whether they did or did not log in every day and complete the therapy, but that their therapy practice time would be recorded by the software. Participants were seen in the clinic on a weekly basis to review and monitor progress.

Analysis of Patient Performance and Progress
One of the key aspects of the software platform is that the clinician can remotely analyze each patient's progress from his or her clinician account. During the weekly clinic sessions, the clinician would decide to continue the participant on the same task or to modify the treatment plan based on the patient's performance. If the participant achieved 95% or higher accuracy two times in succession, the clinician would either progress the

next level of difficulty (e.g., addition level 1 to addition level 2) or would progress to a different task (e.g., assign category identification after category matching). If participants performed at low accuracies (40% or lower) over several sessions, that therapy task was replaced with another task from the task list. Data for each patient's accuracy and latency were plotted over for every session they performed the therapy task for every week up to 10 weeks. Fig. 1 shows a representative sample of participant 84's overall treatment plan in a snapshot, indicating how therapy tasks were assigned during the period of treatment and the overall accuracy for that task each session. As can be seen, therapy tasks are introduced and removed from the patient's therapy schedule based on performance. In addition, for each patient, for each treatment task, a trend line was computed on the time series data and the coefficient of determination (R^2) was

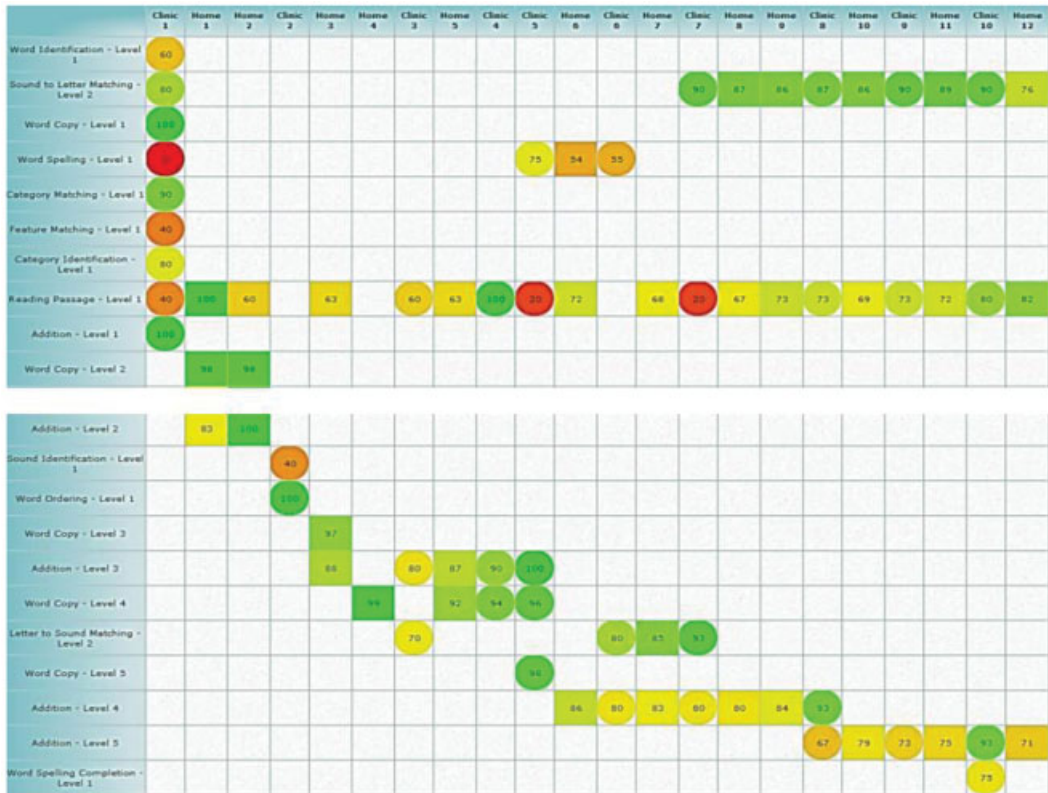


Figure 1 Overall performance of patient 84 on accuracy for all the therapy tasks assigned. The x-axis indicates the schedule for each week and whether the session was at home or in the clinic. The y-axis indicates all the therapy tasks assigned. Cells indicate the patient accuracy (e.g., 89%) and cell colors indicate the population mean: green indicate patient performance is above the population mean, red, yellow and orange indicate the patient performance in below the population mean.

Table 1 Standardized Test Performance for Four Patients, Pre- and Posttreatment

	<i>n</i>	Patient 84		Patient 108		Patient 25		Patient 05	
		Pre (%)	Post (%)	Pre (%)	Post (%)	Pre (%)	Post (%)	Pre (%)	Post (%)
Fluency total	20	45.00	75.00	95.00	100.00	60.00	65.00	95.00	95.00
Auditory comprehension total	200	53.00	69.00	96.50	93.00	66.50	79.50	98.00	94.00
Repetition total	100	84.00	85.00	92.00	96.00	66.00	75.00	92.00	94.00
Naming and word finding total	100	24.00	34.00	90.00	93.00	63.00	58.00	85.00	93.00
Reading total	100	13.00	33.33	84.00	84.00	52.00	52.00	86.0	84.0
Writing total	100	25.00	42.50	73.00	89.00	34.5	37.5	46.0	74.0
Apraxia	60	90.00	98.33	98.33	100.00	95.00	88.33	98.33	100.00
Constructional, visuospatial total	100	18.50	42.00	53.00	62.00	69.00	65.00	84.00	91.00
WAB Language Quotient	38	50.12		90.3	92.1	61.9	66.5	86.8	89.7
WAB Cortical Quotient	45.05	61.58		88.53	91	66.45	69.68	89.78	92.35
WAB Aphasia Quotient	50.2	67.6		93.7	96.4	63.2	68.5	93	94.2
Cognitive Linguistic Quick Test									
Attention	215	8.84	36.28	33.49	45.58	78.60	79.07	87.44	92.56
Memory	185	57.84	64.86	68.65	80.00	45.41	54.05	83.24	87.57
Executive functions	40	7.50	15.00	25.00	27.50	47.50	55.00	65.00	70.00
Language	37	40.54	43.24	72.97	78.38	40.54	45.95	67.57	78.38
Visuospatial skills	105	16.19	28.57	31.43	37.14	74.29	80.95	85.71	91.43
Composite severity	20	25.00	35.00	60.00	75.00	75.00	80.00	90.00	100.00
Clock drawing	13	0.00	0.00	61.54	76.92	46.15	61.54	100.00	92.31
Boston Naming Test	60	0.00	3.33	93.33	95.00	13.33	36.67	73.33	80.00
Pyramids and Palm Trees test	52	63.46	65.38	82.69	90.38	78.85	78.85	96.15	98.08

Results are provided for the WAB, Cognitive Linguistic Quick Test, Boston Naming Test, and Pyramids and Palm Trees test. Test scores are provided for the total number of items. See text for details. Abbreviation: WAB, Western Aphasia Battery.

computed. $R^2 > 0.2$ indicated a linear trend in data (for both accuracy and latency).

Case Studies Implementing This Treatment Workflow

In this section, we review four cases from our ongoing data collection efforts.

EXAMPLE 1: LOW LANGUAGE PROFILE, LOW COGNITIVE PROFILE

The first patient, No. 84, is a 66-year-old man who suffered a stroke ~14 months prior to participation in this study. This participant presented with low performance on both language and cognitive measures. Therefore, as seen in Table 1, this participant's LQ was 38 and AQ was 50.2. This participant also presented with a low CQ (45.05) and generally low scores on all aspects of cognitive processing including atten-

tion, memory, executive functions, and visuospatial processing on the CLQT. Oral naming was severely impaired. This patient was assigned the following tasks in treatment: category matching, feature matching, picture naming, rhyming, sound identification, word identification, sound-to-letter matching, and word copy to work on various aspects of naming, reading, and writing within language processing; and picture matching and symbol cancellation to work on attention, memory, and visuospatial aspects of cognitive processing. Note that these tasks were assigned to this participant over the course of the 10-week period, and for some tasks, such as symbol matching and word copy, the patient progressed to the next level. Fig. 2A shows a representative sample of this participant's progression through word copy (level 2) where improvements in accuracy are accompanied by increased latency on the task. This patient

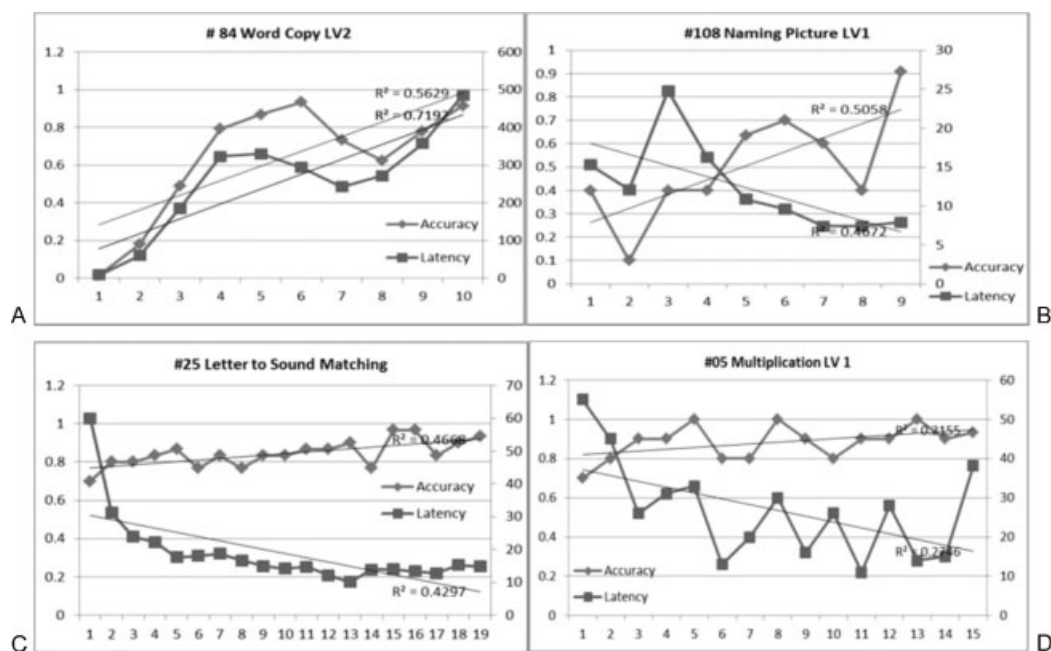


Figure 2 (A) Performance on accuracy and latency for patient 84 on one task: word copy level 2; (B) performance on accuracy and latency for patient 108 on one task: naming pictures; (C) performance on accuracy and latency for patient 25 on one task: letter-to-sound matching; and (D) performance on accuracy and latency for patient 05 on one task: multiplication level 1. For all graphs, accuracy is indicated on the left y-axis, latency is indicated on the right y-axis. the x-axis indicates number of sessions the task was completed. Linear slopes and R^2 values are plotted for accuracy and latency.

completed 48 therapy sessions (i.e., logged in to complete the therapy assignment) over the course of 10 weeks. At the end of treatment, this participant was tested on all the standardized measures and showed improvements in LQ (38 to 50.1) CQ (45.0 to 61.5), AQ (50.2 to 67.6), as well as improvements on all subtests of CLQT including attention (8 to 36.2%), memory (57.8 to 64.8%), executive function (EF) (7.5 to 15%), visuospatial skills (16.1 to 28.5%) and on the BNT (0% to 3%).

EXAMPLE 2: HIGH LANGUAGE PROFILE, LOW COGNITIVE PROFILE

The next patient, No. 108, was a 75-year-old man who suffered a stroke 29 months prior to participation in this study. This participant presented with high performance on language subtests but low performance on cognitive measures. That is, this participant's LQ was 90.3 and AQ was 93.7. Patient 108 presented with a lower CQ (88.5) and generally low scores on attention, executive functions, and visuospa-

tial processing on the CLQT. This patient was assigned the following tasks in treatment: picture spelling and picture naming to address language processing and clock reading and instruction sequencing, picture ordering, sound matching, symbol matching, voicemail to address attention, visuospatial processing, and executive function deficits. Note that these tasks were assigned to this participant over the course of the 10-week period, and he progressed multiple levels of difficulty on picture spelling (levels 1 to 3) and symbol matching (levels 1 to 2). Fig. 2B shows a representative sample of this participant's progression on a picture naming task.* As accuracy on the task improved over the course of 11 weeks, latency also decreased. At the end of treatment, this participant was tested on all the standardized measures and showed improvements in LQ

* We should point out that patient 108 served as a control in this study, hence he did not complete treatment sessions at home and was seen weekly once by the clinician for 10 weeks.

(90.1 to 92.1) CQ (88.5 to 91), AQ (93.7 to 96.4), as well as improvements on all subtests of CLQT including attention (33.4 to 45.58%), memory (68.6 to 80.0%), EF (25 to 27.5%), visuospatial skills (31.4 to 37.14%) and on clock drawing (61.5 to 76.9%).

EXAMPLE 3: LOW LANGUAGE PROFILE, HIGH COGNITIVE PROFILE

Our third patient, No. 25, is a 77-year-old man, who suffered a stroke 168 months and a secondary traumatic brain injury ~60 months prior to participation in the study. Based on standardized tests, this participant presented with low performance on language subtests but relatively higher performance on cognitive measures. That is, this participants' LQ was 61.9, CQ was 66.4, and AQ was 63.2. This participant presented with moderate scores on memory and language subtests on the CLQT and was within normal limits for performance on attention, EF, and visuospatial skills. This patient was assigned the following tasks in treatment: category identification, category matching, feature matching, letter-to-sound matching, reading passage, sound identification, sound-to-letter matching, word copy, and word spelling to address language processing and addition and word ordering to address working memory. Over the 10 weeks of the study, this patient completed 73 sessions (i.e., logged in to complete the therapy assignment). During this period, the patient progressed to the next levels for several tasks including such as addition (level 1 to 5), word copy (level 1 to 5). Fig. 2C shows a representative sample of this participant's progression through letter-to-sound matching; as accuracy on the task improved, latency also decreased. At the end of treatment, this participant was tested on all the standardized measures and showed improvements on the LQ (61.9 to 66.5%) CQ (66.4 to 69.6%), AQ (63.2 to 68.5), as well as improvements on all subtests of CLQT.

EXAMPLE 4: HIGH LANGUAGE PROFILE- HIGH COGNITIVE PROFILE

Patient 05 was a 56-year-old man who suffered a stroke 147 months prior to his participation in the study. This participant presented with high language and cognitive skills, based on stan-

dardized tests. Thus, this participants' LQ was 86.8, CQ was 89.7, and AQ was 93. This participant shows high performance on all subtests of the CLQT including attention, memory, EF, and visuospatial skills. This patient was assigned the following tasks in treatment: category matching, feature matching, letter-to-sound matching, sound-to-letter matching, map reading, picture spelling, reading passage, rhyming, sound identification, syllable identification, word spelling to address language processing and addition, subtraction, multiplication, division, picture ordering, word ordering, and word problems to address cognitive processing. During the course of 10 weeks, this participant completed 89 therapy sessions. Again, this patient progressed through several levels for various tasks including addition (level 1 to 4), map reading (level 1 to 3), multiplication (level 1 to 2), picture spelling (level 1 to 3), subtraction (level 1 to 2), word spelling (level 1 to 5) during the course of treatment. Fig. 2D shows a representative sample of this participant's progression through multiplication level 1. At the end of treatment, this participant was tested on all the standardized measures and showed improvements on the LQ (86.8 to 89.7), CQ (89.7 to 92.3), AQ (93 to 94.2, BNT (73 to 80%), as well as improvements on all subtests of CLQT with the exception of clock drawing.

DISCUSSION

The present study was aimed at developing an impairment-based, individualized treatment plan for patients that can be delivered through an iPad. Using research evidence published for rehabilitation of various aspects of brain damage, we first developed a series of tasks targeted at addressing specific aspects of language and cognitive processing. These tasks were implemented into a software platform (Constant Therapy) to provide individualized therapy for individual patients enrolled in the study. The four case studies described describe how therapy can be targeted for an individual with low cognitive and language performance, high language and low cognitive performance, high cognitive and low language performance, and high language and cognitive performance.

These examples are simply four benchmarks; however, most patients obviously fall somewhere along these two dimensions. Importantly, the range of tasks described in this article illustrates the breadth of impairment-based language and cognitive rehabilitation that can be provided to patients.

Preliminary results from four patients provide some interesting observations. First, all participants improved in their iPad-based therapy tasks in general, both terms of accuracy and well as latency on the tasks (however, see exception about patient 84 who increased in his latency). A complete description of the progression of each therapy task for each patient is out of the scope of this article; however, all participants had at least one or two tasks that they did not improve during the course of the study. Nonetheless, participants showed changes on standardized tests, although the amount of change was variable: patient 84 showed improvements on both language and cognitive measures, patient 108 showed more improvements on cognitive measures, patient 25 did not show much improvement on most tasks excepts naming on the BNT, and patient 05, who had high performances before treatment, showed some subtle changes in cognitive measures and in reading. There are two important aspects that likely contribute to the improvements observed. First, therapy was targeted at specific aspects of language and cognitive processing that were deemed to be impaired during the standardized tests. As an example, patient 84 presented with severe language impairments; therapy targeted at copying words of different lengths improved as a function of treatment. This patient also showed notable improvements on the writing subtest of the WAB (which measures copying words/sentences among other things). Likewise, patient 05, who presented with relatively high cognitive and language skills, practiced multiplication among other therapy tasks and demonstrated improvements not only on that task, but also showed improvements on the subtests of the WAB that assessed calculation. Therefore, impairment-based therapy when targeted toward the right language/cognitive skill can be improved, even in seemingly chronic patients.

A second and noteworthy observation was that when participants were encouraged to complete homework practice in addition to their clinic sessions, they appeared to be very diligent and motivated in completing therapy at home. Thus, patient 84 completed 48 therapy sessions, patient 25 completed 73 therapy sessions, and patient 05 completed 89 therapy sessions. Patient 108 was a control participant (thus he only completed the therapy during his weekly therapy session), but even this individual was very motivated to complete therapy and showed improvements on the standardized tests. Therefore, participant motivation to complete the therapy was likely another factor that facilitated the positive findings in this study. Clearly, a caveat to these results is that all four cases discussed here have shown remarkable improvements. A larger study underway will allow us to systematically examine the amount of improvements as a function of therapy practice.

In the meantime, there are some tentative preliminary conclusions we can draw from this study. There is a huge need to continue long-term therapy for individuals with chronic brain damage; however, insurance limits to therapy reimbursement and physical limitations are huge barriers for these individuals to effectively obtain continued rehabilitation services. Recent technological advances, especially smart tablets and Internet-based applications, provide a unique way to empower these individuals to take control of their rehabilitation, by providing them access to these technologies. The key part of access to tablet- and mobile-based technologies is the collaborative and interactive aspect that allows patients to continue therapy outside the traditional clinical setting, such as at their home, and stay connected with their clinician to manage their rehabilitation program. These advances in technologies have the potential to reshape the way rehabilitation is conducted for individuals who require ongoing communication therapy but struggle to find practical and financially viable options to continue their rehabilitation. As Van de Sandt-Koenderman notes, "The role of the clinician will then shift to one of an advisor and orchestrator of the rehabilitation process. Based on careful diagnostics at all three levels of aphasia rehabilitation, the clinician can choose which treatment

approach is needed and offer relevant treatment programs that enable the client to work on his or her own rehabilitation, independently and at his or her own pace."^{5(p. 26)} For researchers in rehabilitation research, the ability to use these emerging technologies provides new and exciting opportunities to examine the effectiveness of different rehabilitation approaches.

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Appendix 1 A Description of the Different Language and Cognitive Therapy Tasks, Their Hypothesized Cognitive/Language Operation, and the Supporting Research Evidence

Therapy Type	Cognitive/Language Operation and Supporting Evidence
Naming Therapy	
Rhyme judgment	Retraining phonological encoding and processing ^{18–20}
Syllable identification	Retraining phonological segmentation ²¹
Sound identification	Retraining phonological processing ^{22–24}
Category matching	Semantic categorization to strengthen semantic boundaries ^{26–28}
Feature matching	Analysis of semantic features to strengthen semantic representations ^{12,13,29–32}
Picture naming	Retrieving semantic-phonological representations of words ^{7,33–35}
Reading therapy	
Spoken word–written identification	Auditory word recognition ³⁶
Written word category identification	Word semantic relatedness judgment to strengthen semantic associations ³⁷
Reading passages	Retraining sentence and story comprehension ^{38–41}

(Continued)

Appendix 1 (Continued)

Therapy Type	Cognitive/Language Operation and Supporting Evidence
Long passage reading comprehension	Retraining sentence and story comprehension with longer passages ²⁶
Writing therapy	
Word copy completion	Retraining orthographic representations ^{42–47}
Word copy	Retraining orthographic representations with some letters provided—same as word copy
Word spelling completion	Retraining orthography using phoneme-to-grapheme conversion with some letters provided ^{29,48,49}
Word spelling	Retraining orthographic access and phoneme-to-grapheme conversion—same as word spelling completion
Picture spelling completion	Retraining orthographic access and phoneme-to-grapheme conversion with some letters provided ⁵⁰
Picture spelling	Retraining orthographic access and phoneme-to-grapheme conversion with some letters provided
Sound-to-letter matching	Retraining phoneme-to-grapheme conversion skills ^{31,51,52}
Letter-to-sound matching	Retraining grapheme-to-phoneme conversion skills ^{34,53}
Sentence planning	
Active and passive sentence completion	Retraining simple sentence construction using active and passive sentences ^{54–57}
Visuospatial processing	
Symbol cancellation	Retraining visuospatial scanning, attention to visual stimuli ^{58–60}
Telling time/analog clock	Retraining strengthening of visuospatial information such as clock ⁷¹
Reading maps	Retraining strengthening visuospatial organization and analytical skills ^{62,63}
Memory	
Visuospatial picture/written word/spoken matching	Incrementally retraining visuospatial working memory for picture, written word or spoken stimuli ^{64–66}
Voicemail task	Retraining auditory working memory using a functional task ^{51,67}
Attention	
Response inhibition	Retraining sustained attention and response inhibition ⁶⁸
Symbol cancellation	Retraining visuospatial scanning, attention to visual stimuli ^{43–45}
Problem solving	
Alphabetical word/picture ordering	Retraining verbal working memory and analytical reasoning skills to sort words/pictures alphabetically ⁶⁹
Arithmetic tasks (addition, subtraction, etc.)	Strengthening non-linguistic cognitive processing and working memory ^{70–75}
Quantitative reasoning	
Word problem	Verbal and analytical reasoning to complete mathematical solutions
Executive function	
Instruction sequencing	Strengthening goal directed planning and organization for functional information ⁷⁶