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Case Report Open Access

Detecting Small and Large Fluctuations in Language and Cognitive Performance: A Longitudinal Rehabilitation Case Study

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Abstract

There are very few studies that longitudinally track the recovery of stroke survivors after their discharge from the hospital. In this case study, we report a longitudinal profile of an individual with post-stroke aphasia, who received continuous rehabilitation through an iPad based therapy delivery platform. One month after the onset of his stroke, this individual was able to practice therapy at home using the iPad software on a daily basis and continued to make daily gains in specific prescribed therapy tasks. During the course of his rehabilitation, however, he suffered a second stroke, which was detected by changes in performance on the therapy tasks. Subsequent to the second stroke, this individual resumed therapy practice and continued to make gains on language and cognitive functions. Over the course of a year, the patient logged in 291 days and practiced 31 language and cognitive tasks. This case study provides a unique opportunity to demonstrate for the first time that (a) it is possible to detect the onset of a (recurrent) stroke due to changes in language and cognitive performance in terms of accuracy and latency even before a confirmatory diagnosis, and (b) improvements in language and cognitive abilities are possible with systematic and continued practice. Detecting small and large fluctuations in language and cognitive performance in post-stroke aphasia: A longitudinal rehabilitation case study.

Keywords: Aphasia; Stroke rehabilitation; Recurrent stroke; predicting outcomes

Introduction

According to National Institutes of Neurological Disorders and Stroke, nearly three-quarters of all strokes occur in people over the age of 65 and the risk of having a stroke more than doubles each decade after the age of 55. Therefore, the incidence of stroke is increasing proportionately with the increase in the aging population. According to the National Aphasia Association, approximately 80,000 individuals acquire aphasia each year from strokes, and naming deficits are the most common language deficits in post-stroke aphasia. In addition, strokes are a common cause of long term disability and many of these individuals suffer from aphasia for the rest of their lives. There are very few studies that longitudinally track the recovery of stroke survivors after their discharge from the hospital. The few studies that have followed stroke survivors over time, have mostly examined outcomes for stroke survivors' integration into their natural environment, homes, and community. Consequently, these studies have mostly been qualitative assessments of burdens to progress and patients' expectations of their own psychosocial progress [1,2]. Only one study has chronicled the language/behavioral profile of a post-stroke individual with aphasia over the course of seven years [3], and this study provides a quantitative and qualitative description of the improvements in language components over a period of time and their impact on this individual's quality of life.

There are yet no studies that have chronicled the time course of specific individuals' language recovery based on their behavioral profiles and as a function of rehabilitation. On the other hand, there are several studies that have demonstrated the beneficial effects of rehabilitation in the acute stages after stroke [4,5] as well as in the chronic stages after stroke [6,7]. Recently, a review of randomized control trials of treatment studies in chronic post-stroke individuals found that treatment outcomes for individuals in the chronic phase (6 months or longer post stroke) was quite robust, which was contrary to popular belief and skepticism about the effectiveness of treatments in chronic post-stroke individuals [7,8]. This is augmented by another review that has found that intensity of aphasia therapy is a positive prognosticator for overall long term recovery [9].

In this case study, we report a longitudinal profile of an individual with post-stroke aphasia, who received continuous rehabilitation through an iPad based therapy delivery platform. Therefore, this individual was able to practice therapy at home on a daily basis and continued to make daily gains in specific prescribed therapy tasks. During the course of his rehabilitation, however, he suffered a second stroke, which was detected by changes in performance on the therapy tasks. Even though the risk of stroke reoccurrence within the first year of the first stroke is reported to be high [10,11], and there are several approaches to predicting the risk of a recurrent stroke [12], there are yet no ways of detecting, identifying and intervening a recurrent stroke in stroke survivors who are at risk but are not under medical supervision. This case study illustrates a novel and unique opportunity, due to the continuous data collection of therapy performance, to detect changes in behavior as a predictor to the recurrence of a second stroke.

Therefore, in this case study we describe the language/cognitive behavioral performance of an individual after an initial stroke in the left parietal region followed by second stroke in the left frontal region. This case study is divided into three phases: (a) rehabilitation after stroke 1, (b) change in behavior and performance as a result of stroke 2, and (c) rehabilitation after stroke 2.

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Case Report

BUMA99 was a 71 year old right handed male individual who suffered a unilateral Left CVA stroke in December of 2012. Per the medical history, a single acute stroke in the left posterior parietal region was identified on 12/26/2012. No MRI was available to report at this time. At the time of the stroke, he was a retired educator living in New Hampshire, USA and commuted to the Aphasia Research Laboratory at Boston University, Boston, Massachusetts for the face-to-face evaluation and treatment sessions. This included the initial evaluations between January-February, 2013 for language and cognitive deficits as well as other follow up visits as indicated below. Several standardized tests were administered including the Western Aphasia Battery-Revised [13], Boston Naming Test [14], Pyramids and Palm Trees [15] and the Cognitive Linguistic Quick Test [16]. The results of these tests are provided in Table 1. Based on these tests, BUMA99 had a global aphasia, with significant deficits in spoken fluency, auditory comprehension of yes/no question, single words, objects and sequential commands, repetition, and spoken naming. Reading single words was a relative strength as was writing letters of the alphabet and copying single words. On the CLQT, performance revealed an overall moderate impairment with severe impairment in memory and language, mild impairments in attention, executive functions and no impairment in visuo-spatial skills. A test of non-verbal semantic processing (PAPT) revealed a relative strength (82% accuracy). In addition, the ASHA FACS (Functional Assessment of Communication Skills for Adults), was administered to evaluate this individual's functional communication abilities on a variety of communication domains rated on a scale of 1-7 (1-cannot do, 7- does independently). In the domains of social communication, reading, writing basic concepts, he was reported to be able to complete tasks with moderate assistance (range 4-5), whereas in the domains of communication of basic needs and planning, he was reported to able to complete the tasks with minimal assistance (6-6.15). During the course of the evaluation period of this report, he reportedly received periodic but inconsistent speech therapy services from a private speech therapist (Figure 1).

Methods

Description of the therapy program

This patient was initiated on a home based treatment program Constant Therapy (www.constanttherapy.com) on an iPad in January, 2013 to receive therapy. The choice of therapy tasks to be assigned came from a set of 50+ therapy tasks broadly divided in language and cognitive therapy. All these tasks are delivered through the Constant Therapy software platform and are performed on an iPad. Due to page limitations, the reader is referred to Kiran et al., for a comprehensive description of this therapy platform and its utility as a telerehabilitation tool for patients with brain damage. In this study, the patient worked on the following language and Cognitive therapy tasks:

Naming /auditory comprehension therapy tasks

Word identification: In this task, the patient hears a word and is asked to match it to the corresponding written word from four choices.

Spoken word comprehension: In this task, the patient was asked to match a spoken word to its corresponding picture from a choice of four.

Feature matching: In this task, the patient was asked to judge whether the semantic feature is applicable to the target picture.

Sound identification: In this task, the patient was asked to judge whether a target picture contains a specific phoneme/sound.

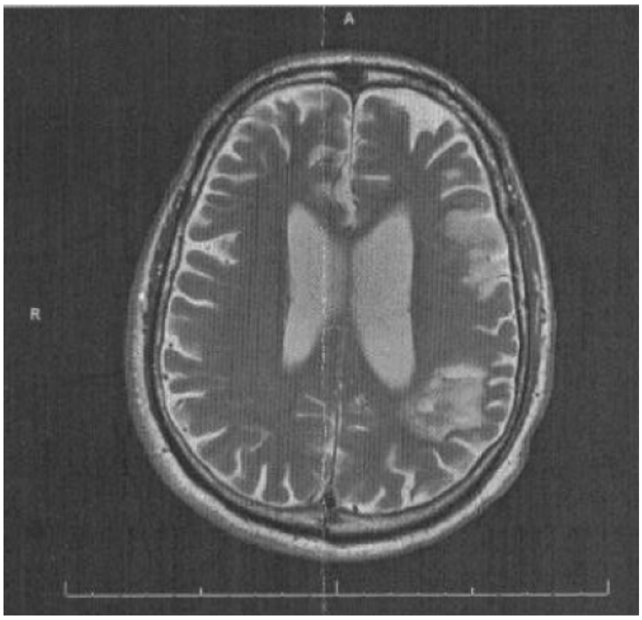

Figure 1: MRI of patient performed 5/2/2013 reveals two infarcts, a chronic left posterior parietal infarct and an acute left frontal infarct.

Western Aphasia Battery	**Month/Year: 1/28/13**			
Spontaneous Speech				
Information Content	10	2	20.00%	
Fluency	10	2	20.00%	
Total	20	4	20.00%	
Auditory Verbal Comprehension				
Yes/No Questions	60	6	10.00%	
AuditoryWord Recognition	60	17	28.33%	
Sequential Commands	80	0	0.00%	
Total	200	23	11.50%	
Repetition				
Total				
Verbal Apraxia Rating	100	0	0.00%	
Naming and Word Finding				
Object Naming	60	5	8.33%	
Word Fluency	20	0	0.00%	
Sentence Completion	10	1	10.00%	

Responsive Speech	10	0		
Total	100	6	6.00%	
Reading				
Comprehension of Sentences	40	26	65.00%	
Reading Commands	20	0	0.00%	
Written Word - Object Matching	6	6	100.00%	
Written Word - Picture Matching	6	6	100.00%	
Picture - Written Word Matching	6	6	100.00%	
Spoken Word - Written Word Matching	4	3	75.00%	
Letter Discrimination	6	1	16.67%	
Spelled Word Recognition	6	0	0.00%	
Spelling	6	0	0.00%	
Writing				
A. Writing on request	6	5.5	91.67%	
B. Written Output	34	0	0.00%	
C. Writing to Dictation	10	0	0.00%	
D. Writing Dictated Words	10	1	10.00%	
E. Alphabet and Numbers	22.5	17.5	77.78%	
F. Dictated Letters and Numbers	7.5	0	0.00%	
G. Copying a Sentence	10	10	100.00%	
Apraxia				
Total	60	36	60.00%	
Constructional, Visuospatial, and Calculation				
A. Drawing	30	16	53.33%	
B. Block Design	9	9	100.00%	
C. Calculation	24	20	83.33%	
D. Raven's Colored Progressive Matrices	37	25	67.57%	
Total	100	70	70.00%	
Total	40	0	0.00%	
Language Quotient	100	23.3		
Cortical Quotient	100	28.1		
Aphasia Quotient	100	11.5		
Aphasia Type	Global			
CLQT				
attention	215	175	81.40%	Mild*
memory	185	60	32.43%	Severe
executive functions	40	23	57.50%	Mild*
language	37	1	2.70%	Severe
Visuospatial skills	105	93	88.57%	WNL*
Composite severity	20	12	60.00%	Moderate
Clock drawing	13	11	84.62%	Mild
Boston Naming Test	60	3	5.00%	
Pyramids and Palm Trees (3 Pictures)	52	43	82.69%	

Table 1: Standardized Test Performance subsequent to Stroke 1 performed in January, 2013.

Reading therapy tasks

Written word comprehension: In this task, the patient is asked to match a written word to its corresponding picture from a choice of four.

Written word category identification: In this task, the patient is shown a picture and is asked to pick the correct superordinate category from three choices.

Sound-letter matching: In this task, the patient selects the appropriate letter that matches the spoken sound. There are two levels of this task, which have increasingly difficult distractors.

Letter to sound matching: In this task, the patient selects the appropriate spoken sound that matches a written letter. There are two levels of this task, which have increasingly difficult distractors.

Category identification: In this task, the patient has to decide if two written words are related in meaning or not.

Writing therapy tasks

Word copy: In this task, the patient has to copy a written word by moving letter tiles to their corresponding positions. There are five levels of this task which differ in the length of the words and distractor letters.

Word spelling completion: In this task, the patient has to write the spelling of a spoken word by moving letter tiles to their corresponding positions, certain target letters are already provided. There are five levels of this task which differ in the length of the words and distractor letters.

Word spelling: In this task, the patient has to write the spelling of a spoken word by moving letter tiles to their corresponding positions. There are five levels of this task which differ in the length of the words and distractor letters.

Picture spelling completion: In this task, the patient has to write the spelling of a picture by moving letter tiles to their corresponding positions, certain target letters are already provided. There are five levels of this task which differ in the length of the words and distractor letters.

Picture spelling: In this task, the patient has to write the spelling of a picture by moving letter tiles to their corresponding positions, certain target letters are already provided. There are five levels of this task which differ in the length of the words and distractor letters.

Sentence planning therapy tasks

Active sentence completion: In this task, the patient completes an active sentence by arranging word phrase segments in the correct grammatical order. There are two levels of this task which differ in the nature of distractors.

Passive sentence completion: In this task, the patient completes a passive sentence by arranging word phrase segments in the correct grammatical order. There are two levels of this task which differ in the nature of distractors.

Visuo-spatial processing therapy tasks

Clock reading: In this task, the patient is asked to read an analog clock and select the correct answer from three choices.

Symbol cancellation: In this task, the patient is asked to find all symbols on a grid that matches a target symbol presented. There are 10 levels of this task. With each increasing level, the symbol and the search grid increase in difficulty.

Map reading: In this task, the patient is asked to navigate through a two-dimensional map to answer specific questions about landmarks and geographical locations. There are three levels of this task, with each increasing level, the distractors become more difficult.

Attention therapy tasks

Playing card slapjack: In this task, the patient is shown a target playing card and is asked to tap the iPad screen every time this playing card is repeated.

Memory therapy tasks

Visuo-spatial picture memory matching: In this task, the patient is asked to find matching picture pairs on a grid by memorizing their location. There are five levels in this task, with each increasing level, the grid size increases, increasing the number of items to be memorized.

Word memory matching: In this task, the patient is asked to find matching word pairs on a grid by memorizing their location. There are five levels in this task, with each increasing level, the grid size increases, increasing the number of items to be memorized.

Visuo-spatial auditory memory matching: In this task, the patient is asked to find matching spoken word pairs on a grid by memorizing their location. There are five levels in this task, with each increasing level, the grid size increases, increasing the number of items to be memorized.

Environmental sound matching: In this task, the patient is asked to find matching environmental sound pairs on a grid by memorizing their location. There are five levels in this task, with each increasing level, the grid size increases, increasing the number of items to be memorized.

Voicemail task: In this task, the patient is asked to listen to a 5-10 second voicemail message and answer corresponding questions about the content.

Problem solving therapy tasks

Alphabetical word ordering: In this task, the patient is asked to sort a set of words in alphabetical order. There are five levels in this task. With each increasing level, the number of items to be sorted increases.

Arithmetic with subtasks: such as (i) addition (the patient has to add a given set of 1-3 digit numbers and enter his response into a number pad), (ii) subtraction (the patient has to subtract a given set of 1-3 digit numbers and enter his response into a number pad), (iii) multiplication (the patient has to multiply a given set of 1-3 digit numbers and enter his response into a number pad), (iv) division (the patient has to divide a given set of 1-2 digit numbers and enter his response into a number pad). There are five levels in each arithmetic task. With each increasing level, the number of digits for computation increases.

Quantitative reasoning using currency: In this task, the patient has to calculate the amount of money represented by a given set of currency notes and coins. There are four levels in this task. With each increasing level of difficulty, the arithmetic to be computed increases.

Executive function therapy tasks

Instruction sequencing: In this task, the patient has to sequence a given set of steps in the correct order to complete a functional procedural task.

Each of these tasks consist of a range of stimuli (min = 150, max = 600) and therefore, in each consecutive therapy session, few to no items are repeated. During the initial session, a subset of potential therapy tasks was assigned to BUMA99 as baselines. If performance on a task was below 80% accuracy, that task was assigned for therapy. In several cases, tasks higher than 80% accuracies were still assigned for therapy when it was determined that the patient's latency was very long on the task. Once the initial therapy tasks were assigned, BUMA99 was provided with a username and password to log into the Constant Therapy app and was then asked to practice the therapy up to 7 days a week for one hour each week.

Both accuracy and latency were assessed as dependent measures. When BUMA99 performed higher than 90% on a particular task, the next level of difficulty of that task was assigned. If he performed at low accuracies (40% or lower) over several sessions, that therapy task was replaced with another task from the task list. Most of the changes in therapy schedule were completed remotely, without the patient having to visit the Aphasia Research Laboratory. Over the course of the year, the patient was seen for 9 one-one individual sessions (1/14/2013, 1/28/2013, 2/13/2013, 2/25/2013, 3/11/2013, 3/25/2013, 5/20/2013, 6/18/2013, 8/8/2013). During the one-one individual sessions, the patient was seen in the clinic for approximately an hour, at which time, the clinician modified the treatment protocol according the patient's performance as well as his feedback. The remainder of the time, the patient performed therapy sessions once or twice a day for a total of 291 days over the course of the year (see Figure 2 for daily log of patient activity) (Figure 2).

Results

Phase I: Rehabilitation after stroke 1

During the initial assessment on 1/14/2013, the following tasks were assigned, word copy- level 1, word identification, addition- level 2,

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clock reading, and category matching (Figure 3). As noted before, as performance improved, therapy tasks were routinely modified.

The following tasks were assigned to the patient between 1/2013 and 4/2013- addition level 1,2, clock reading, word copy, subtraction, sound to letter matching, multiplication, letter to sound matching, feature matching, division, category matching, category identification, symbol matching, and picture matching.

During this time, the patient showed improvement on several tasks, moving to the next level of the task (see supplementary data for patient performance in terms of accuracy and latency by task, level and schedule).

Specifically, as seen in Table 3, performance improved on several tasks including word copy - level 1, addition - level 2, clock reading - level 1, subtraction - level 2, division - level 1, letter to sound matching - level 2 (a representative sample therapy time series data is illustrated in Figure 4). In addition to improvements in accuracy, improvements (reduction) in latency were observed on almost all the tasks (Figure 3).

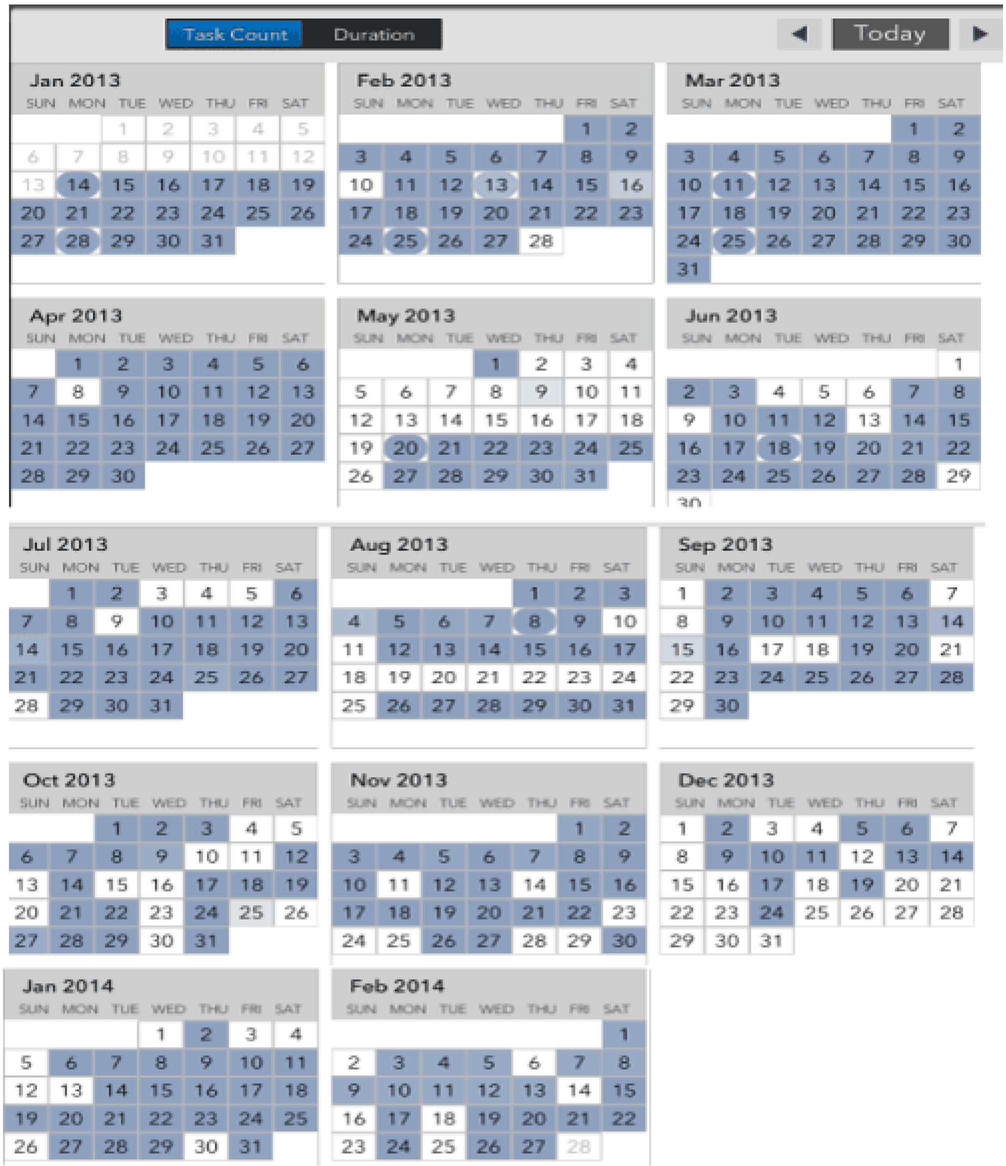

Figure 2: Daily log of patient activity from 1/14/2013 till 2/27/2014 on the Constant Therapy software platform. Blue squares display home practice and blue circles indicate inclinic practice.

Phase II: change in behavior and performance as a result of stroke 2

Towards the end of April, the wife reported that the patient was unable to perform certain therapy tasks, such as word identification, category identification, picture matching, category matching, and multiplication (Figure 5).

Evaluation of the treatment performance revealed that the patient was indeed having difficulty performing tasks, evidenced by reduced

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accuracy and increased latency. Specifically, for certain tasks such as category identification, feature matching and letter to sound matching, performance started declining around 4/28/2013 and BUMA99 was unable to do any of the tasks by 4/30/2013.

For other tasks such as sound to letter matching, picture matching and multiplication, performance decline started on 4/27/13 and by 5/1/2013, performance either declined to 0 or the patient skipped practice of all items because he was unable to complete the tasks. Corresponding increases were observed in latency on these tasks; in some tasks such as multiplication and word identification, response latency almost doubled by 5/1/2013. As can be seen in Table 2, a dramatic decrement in performance from the initiation of therapy is observed in several tasks, including word identification, picture matching, and multiplication (performance changes over 50%).

Notably, during this period, the family did not notice any changes in behavioral and functional performance that would necessitate a medical evaluation.

Subsequent to the very poor performance on several tasks on April, 29th, 2013, the patient visited his family physician on 5/2/2013, and at that time was diagnosed with an acute cerebral infarct and an MRI performed that day confirmed the presence of two strokes (left posterior parietal lobe and left frontal regions; see Figure 1).

	Jan,13	Feb,13	Mar,13	Apr,13	May,13	June,13	July,13	Aug,13	Sep,13	Oct,13	Nov,13	Dec, 13	Jan,14	Feb,14
Addition	✓				✓	✓								
Clock reading	✓			✓	✓	✓								
Word Copy	✓	✓	✓	✓	✓	✓								
Subtraction	✓	✓	✓	✓										✓
Sound to Letter Matching	✓	✓	✓	✓										✓
Multiplication		✓	✓	✓										✓
Letter to Sound Matching		✓	✓	✓							✓	✓		✓
Feature Matching			✓	✓										
Division		✓	✓	✓										
Category Matching	✓	✓		✓	✓		✓		✓					
Category Identification		✓	✓	✓				✓						
Word Identification	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				
Symbol Matching		✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	
Picture Matching		✓	✓	✓	✓	✓	✓	✓	✓	✓				
Word Spelling Completion							✓	✓	✓					
Passive Sentence Completion							✓	✓			✓	✓	✓	✓
Sound Matching									✓	✓	✓	✓	✓	✓
Sound Identification								✓	✓					✓
Active Sentence Completion							✓	✓	✓	✓	✓		✓	✓
Picture Spelling Completion								✓	✓	✓	✓	✓	✓	✓
Word Ordering										✓	✓	✓	✓	✓
Currency Tasks										✓	✓	✓	✓	✓
Spoken Word Comprehension										✓	✓	✓		
Word Matching										✓	✓			
Picture Spelling										✓	✓			
Written Word Comprehension											✓	✓		
Instruction Sequencing												✓	✓	
Playing Card Slapjack												✓		
Voice Mail														✓
Map Reading										✓			✓	
Environmental Sound Matching Tasks													✓	✓

Figure 3: An illustration of all the therapy tasks that were assigned during the course of the therapy.

Phase III: rehabilitation after stroke 2

As shown in Figure 2, after a gap in therapy activity between 5/1/2013 and 5/20/2013, the patient came in to the Aphasia Research Laboratory for a follow-up assessment on 5/20/2013.

At that time four tasks were performed, word identification level 1 (Mean accuracy = 60%, Mean latency = 14 sec) , clock reading level 1 (Mean accuracy = 90%, Mean latency = 10 sec), word copy level 1(Mean accuracy = 100%, Mean latency = 18 sec), category matching level 1 (Mean accuracy = 70%, Mean latency = 11 sec), addition level 1 (Mean accuracy = 80%, Mean latency = 90 sec) and letter to sound matching (Mean accuracy = 40%, Mean latency = 24sec).

From this point, therapy tasks were reassigned based on the new (lower) baseline levels of performance subsequent to the second stroke (Table 2).

Importantly, several tasks were reassigned for therapy and reinitiated at level 1 (or lower levels of difficulty), because BUMA99 was unable to perform tasks at the pre-morbid levels of difficulty. As an example, Figure 5 shows that in the picture matching task, the patient progressed from level 1 to level 2 to level 3 before stroke 2. When the task was reassigned in 6/19/2013, it was reassigned at level 1, thereby reinitiating the progression of tasks after stroke 2, illustrating some regression of behavioral performance as a function of the second stroke.

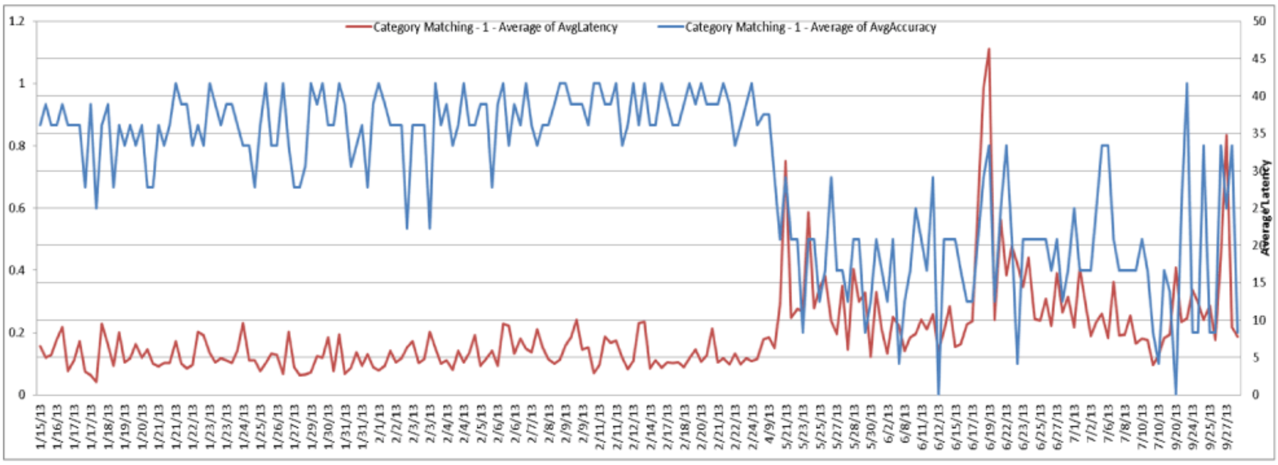

Figure 4: Patient performance on category matching during the period 1/15/2013 to 9/27/2013. X-axis indicates the specific dates of therapy activity, Left Y-axis indicates average latency and Right Y-Axis indicates average accuracy. Details provided in the text.

	Initial (10items)			Final (10 items)		
Task	Date	Accuracy	Latency (s)	Date	Accuracy	Latency (s)
Word Copy - Level 1	1/14/2013	93.3%	19.933	1/24/2013	98.9%	10.533
Addition - Level 2	1/15/2013	60.0%	64.7	1/24/2013	80.0%	41.5
Category Matching - Level 1	1/15/2013	86.7%	6.533	9/28/2013	50.0%	8.45
Clock Reading - Level 1	1/15/2013	80.0%	8.1	6/17/2013	100.0%	9.391
Word Identification - Level 1*	1/15/2013	70.0%	9.6	5/1/2013	0.0%	2.735
Category Identification - Level 1	1/25/2013	50.0%	57	8/30/2013	80.0%	8.399
Subtraction - Level 2	1/25/2013	60.0%	60.7	3/18/2013	100.0%	25.176
Word Copy - Level 2	1/25/2013	100.0%	16.733	1/27/2013	98.9%	17.667
Subtraction - Level 1	1/29/2013	100.0%	8.4	2/12/2013	100.0%	5.293
Word Copy - Level 3	1/29/2013	99.1%	26.933	2/12/2013	98.6%	25.714
Division - Level 1	2/14/2013	86.7%	96.14	4/10/2013	100.0%	13.245
Letter to Sound Matching - Level 2	2/14/2013	50.0%	11.5	12/2/2013	70.0%	10.74
Multiplication - Level 1	2/14/2013	93.3%	19.816	3/18/2013	93.3%	18.816
Word Copy - Level 5	2/14/2013	98.3%	53.972	4/10/2013	100.0%	40.666
Picture Matching - Level 1	2/25/2013	100.0%	20.031	3/7/2013	100.0%	14.689
Sound to Letter Matching - Level 2 *	2/26/2013	60.0%	22.064	4/30/2013	40.0%	4.956
Symbol Matching - Level 6	2/26/2013	97.5%	26.18	3/7/2013	98.0%	15.131
Picture Matching - Level 2	3/7/2013	92.8%	43.885	3/10/2013	83.9%	37.361
Symbol Matching - Level 7	3/7/2013	94.3%	26.646	3/11/2013	98.0%	17.97
Picture Matching - Level 3 *	3/11/2013	70.7%	92.959	5/1/2013	0.0%	1.346
Symbol Matching - Level 10	3/11/2013	89.0%	18.677	4/10/2013	95.0%	32.222

Multiplication - Level 2	3/19/2013	93.3%	46.424	4/1/2013	93.3%	41.784
Subtraction - Level 3	3/19/2013	93.3%	31.35	3/25/2013	100.0%	38.587
Feature Matching - Level 1	3/25/2013	80.0%	8.51	4/1/2013	80.0%	4.161
Subtraction - Level 5	3/25/2013	90.0%	191.855	4/7/2013	70.0%	58.347
Feature Matching - Level 2	4/2/2013	80.0%	2.692	4/30/2013	90.0%	9.328
Multiplication - Level 3 *	4/2/2013	80.0%	70.381	4/30/2013	0.0%	29.14
Addition - Level 1	4/9/2013	90.0%	11.921	6/17/2013	70.0%	54.617
Word Copy - Level 2 (after 2nd stroke)	5/20/2013	94.3%	42.152	6/17/2013	98.2%	20.739
Word Identification - Level 1	5/20/2013	46.7%	14.8	10/27/2013	40.0%	10.42
Clock Reading - Level 2	6/18/2013	100.0%	10.7	6/28/2013	100.0%	9.561
Word Copy - Level 4 (after 2nd stroke)	6/18/2013	97.2%	76.682	6/28/2013	99.4%	65.719
Picture matching - Level 1 (Repeated after 2nd stroke)	6/19/2013	79.5%	18.024	8/3/2013	95.0%	10.536
Symbol Matching - Level 2 (after 2nd stroke)	6/19/2013	98.0%	10.228	6/28/2013	100.0%	9.457
Active sentence completion - Level 1	7/1/2013	77.8%	49.4	1/28/2014	72.5%	9.995
Symbol Matching - Level 3 (after 2nd stroke)	7/1/2013	95.8%	9.902	7/6/2013	97.8%	9.097
Word Spelling Completion - Level 1	7/1/2013	82.5%	24.55	7/24/2013	100.0%	9.899
Symbol Matching - Level 4 (after 2nd stroke)	7/7/2013	88.5%	28.63	7/16/2013	95.6%	9.629
Symbol Matching - Level 5 (after 2nd stroke)	7/16/2013	94.8%	12.69	7/24/2013	100.0%	11.036
Passive Sentence Completion - Level 1	7/25/2013	67.5%	32.08	2/27/2014	91.1%	17.26
Symbol Matching - Level 6 (after 2nd stroke)	7/25/2013	95.0%	37.936	8/13/2013	96.8%	26.958
Word Spelling Completion - Level 2	7/25/2013	76.7%	48.064	9/6/2013	65.8%	25.997
Picture matching - Level 2 (Repeated after 2nd stroke)	8/5/2013	63.1%	56.794	10/3/2013	74.5%	39.646
Picture Spelling Completion - Level 1	8/9/2013	90.0%	12.625	11/7/2013	100.0%	8.87
Sound Identification - Level 1	8/9/2013	70.0%	71.63	2/27/2014	66.7%	4.88
Symbol Matching - Level 7 (after 2nd stroke)	8/14/2013	95.5%	53.751	8/30/2013	93.5%	55.474
Picture Spelling Completion - Level 2	8/31/2013	73.3%	24.37	2/26/2014	82.1%	34.87
Symbol Matching - Level 8 (after 2nd stroke)	8/31/2013	98.8%	14.705	9/6/2013	93.8%	9.904
Sound Matching - Level 1	9/9/2013	72.5%	72.53	2/26/2014	75.0%	54.69
Symbol Matching - Level 9 (after 2nd stroke)	9/9/2013	91.5%	46.417	9/20/2013	96.7%	23.47
Symbol Matching - Level 10 (after 2nd stroke)	9/20/2013	87.0%	32.055	1/31/2014	98.9%	28.86
Active sentence completion - Level 2	10/6/2013	95.0%	11.3	1/31/2014	83.3%	11.55
Map Reading - Level 1	10/6/2013	50.0%	69.9	1/27/2014	20.0%	4.32
Picture Spelling - Level 1	10/6/2013	67.5%	39.617	11/19/2013	65.8%	39.85
Word Matching - Level 1	10/6/2013	70.3%	33.658	11/7/2013	84.4%	16.8
Currency Tasks - Level 1	10/31/2013	100.0%	77.155	11/7/2013	100.0%	17.7
Spoken Word Comprehension - Level 1	10/31/2013	60.1%	32.04	12/14/2013	77.5%	30.33

Word Ordering - Level 1	11/7/2013	58.8%	91.792	2/27/2014	85.7%	34.61
Currency Tasks - Level 2	11/8/2013	100.0%	123.615	11/16/2013	100.0%	86.48
Currency Tasks - Level 3	11/17/2013	90.0%	143.79	2/27/2014	100.0%	86.8
Currency Tasks - Level 4	11/20/2013	80.0%	197.3	1/31/2014	100.0%	100.24
Written Word Comprehension - Level 1	11/20/2013	67.5%	23	12/13/2013	95.0%	12.755
Picture Spelling Completion - Level 3	12/5/2013	49.2%	44.8	2/17/2014	68.5%	45.31
Instruction Sequencing - Level 1	12/14/2013	59.7%	81.62	1/18/2014	54.2%	21.43
Environmental Sound Matching - Level 1	12/24/2013	72.2%	49.58	2/27/2014	70.3%	55.31
Subtraction - Level 3 (Repeated after 2nd stroke)	2/4/2014	70.0%	143.23	2/17/2014	70.0%	161.6
Voice Mail - Level 1	2/4/2014	33.3%	65.85	2/13/2014	33.3%	46.48
Multiplication - Level 1 (Repeated after 2nd stroke)	2/15/2014	77.0%	204	2/27/2014	77.8%	135

Table 2: Performance on the initial 10 items and final 10 items on the various therapy tasks that were assigned over the course of the year. Both accuracy and latency were measured. When noted with an *, patient was unable to complete task due to the onset of the second stroke.

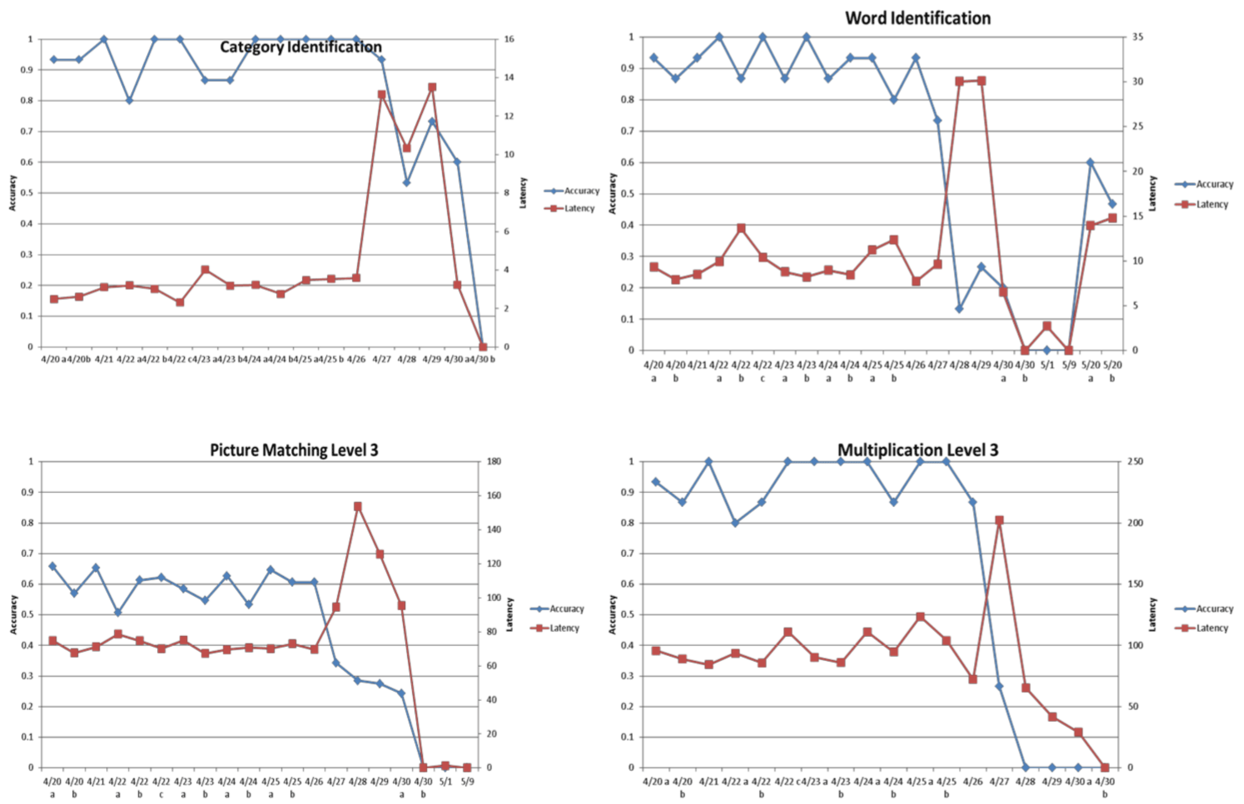

Figure 5: Patient performance between 4/20/2013 and 5/20/2013 on four representative tasks (a) category identification, b) word identification, (c) picture matching level 3 and (d) multiplication level 3. X-axis indicates the specific dates of therapy activity, Left Y-axis indicates average accuracy and Right Y-Axis indicates average latency. As shown, performance on all four tasks declines between 4/27/2013 and 5/1/2013. Corresponding to decreases in accuracy, increases in latency are observed.

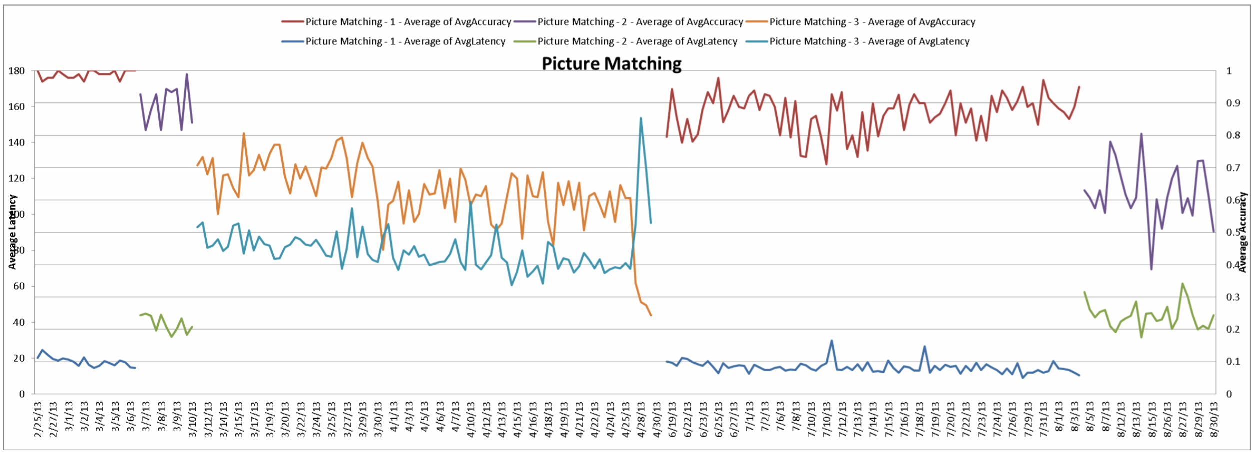

Figure 6: Patient performance on a picture matching task during the period 2/25/2013 and 8/30/2013. X-axis indicates the specific dates of therapy activity, Left Y-axis indicates average latency and Right Y-Axis indicates average accuracy. Details provided in the text.

BUMA99 continued to practice therapy tasks regularly after 5/20/2013 through the rest of the year (Figure 2)[1]. During this time, several new tasks such as spoken word comprehension, written word comprehension, word matching, sound matching, active sentence completion, passive sentence completion, instruction sequencing, sound identification, word spelling completion, picture spelling completion, word ordering tasks, voicemail and currency tasks, were introduced for therapy. Table 2 shows that performance on several of these therapy tasks improved as a function of therapy practice including, word spelling completion-level 1, passive sentence completion-level 1, spoken word comprehension-level 1, word ordering- level 1, written word comprehension- level 1, picture spelling completion- level 3. It should be noted that several of the tasks that BUMA99 is currently performing are those of increased difficulty relative to ones that were completed prior to the onset of stroke 2 and requires mastery of specific lower level tasks and integration of multiple therapy tasks. For instance, picture spelling completion requires the ability to successfully be able to identify and copy single letters (completion of word copy completion) and retrieval of word forms (category identification, word identification). Likewise, instruction sequencing requires successful ability to read single words (category matching) and sentences (active and passive sentence completion).

Discussion

This case report examines the time course of rehabilitation in an individual with post-stroke aphasia over a one year period. During this time, this patient made improvements on several therapy tasks between January and April 2013 as seen in Table 2. The onset of second stroke in the end of April 2013, was detected due to changes in performance in accuracy and latency on the therapy tasks. An MRI scan performed on 5/2/2013 revealed the occurrence of a second stroke. After a brief period, the patient resumed therapy practice on 5/20/2013 and continued to make improvements on several therapy tasks through the course of the year.

This case study provides a unique opportunity to demonstrate for the first time that (a) it is possible to detect the onset of a (recurrent) stroke due to changes in language and cognitive performance in terms of accuracy and latency even before a confirmatory diagnosis, and (b) improvements in language and cognitive abilities are possible with systematic and continued practice. The second observation is very important as these improvements can continue to occur even after the first six months after stroke and after the occurrence of a second stroke.

When the patient was initially evaluated at the Aphasia Research Laboratory in January, 2013, he presented with global aphasia, with significant deficits in spoken fluency, auditory comprehension of yes/no question, single words and objects and sequential commands, repetition, and spoken naming. Additionally, performance on the CLQT indicated mild attention, visuo-spatial and executive function deficits and a severe memory deficit. Although a formal language evaluation was not completed after the second stroke, performance on all the therapy tasks indicate progress on several aspects of language (reading, writing, auditory comprehension, phonological processing) and cognitive skills (visuo-spatial processing, memory and executive function). In addition, the family anecdotally reported overall improvements in social and functional communication over the course of the year.

There are several points worth noting about this case study. First, the role of technology in facilitating the monitoring of a patient's performance continuously but remotely cannot be underestimated. With new technology on mobile devices and data being stored in the cloud, this patient was able to practice most of his therapy at his home while his data was monitored remotely. These advances in technologies have the potential to reshape the way rehabilitation occurs in the future and has been the focus of several recent experimental studies [17-20] and reviews [21-24]. Especially for the patient reported in this study, access to technology such as an iPad resulted in his engagement in therapy at home every day, which compared to the alternative of the typical one day per week of therapy.

[1] With the exception of the gap from 5/1/2013 till 5/21/2013, the only other gap (4 or more days of not using the software) occurs between 8/18/2013-8/25/2013 when the patient went away for a vacation and during 12/24/2013-1/2/2014 which is the Christmas holidays.

Second, with access to technology comes the opportunity to tailor individualized rehabilitation programs based on small and large fluctuations in an individual's performance. As reported in the methods and results, based on the patient's performance during daily therapy practice, tasks were modified to either progress to more difficult level or decrease to an easier level. In other words, in this case study it was possible to capture small fluctuations in therapy performance and adjust the therapy accordingly. As seen in Table 2 and 3, several therapy tasks that were administered after the first stroke (during the period of Jan-April, 2013) were reinstated after the second stroke and repeated through the various levels of difficulty (e.g., picture matching, subtraction, and multiplication). In other cases, new and more complex tasks (e.g., currency tasks, word spelling, word ordering) were introduced during the course of therapy.

Another important observation about individualizing therapy is that even though on some tasks the patient's accuracy is relatively high at initial assignment (e.g., word copy level 1, picture matching level 1), there are clear improvements (reduction in latencies) on these tasks, reinforcing the relearning of these therapy tasks. This is not a trivial observation, because most studies on rehabilitation of aphasia have mostly been focused on improving accuracy in this population, very few studies have examined changes in response times as a function of treatment [25,26].

Most importantly, large fluctuations in performance such as the onset of the second stroke were also detected due to this continuous monitoring of therapy performance. It is likely that the nature of the tasks that were being performed at the time of the second stroke (e.g., word identification, category matching, and multiplication) may have been sensitive to underlying neurological fluctuations at play. Interestingly, examination of Figure 4 (a-d) illustrate that during the period of the presumed onset of the second stroke, decline in behavioral performance was graded (not all or none) over a period of a few days. Whether the decline in language/cognitive performance preceded the onset of the second stroke or coincided with the second stroke cannot be answered in this study, however, the fact that changes in language/cognitive performance can be detected by simple measures such as accuracy and latency on language/cognitive processing is notable. While there are several studies that have described the utility of biomarkers as predictors of stroke onset and progression [27-30], this is the first study to report to changes in language/cognitive function as a predictor of stroke onset.

Importantly, the results of this study when put into the broader context of rehabilitation studies of post-stroke aphasia provide a powerful alternative to current traditional approaches for therapy. First, previous reviews have suggested that more therapy is associated with greater recovery after stroke [9] and this study shows that daily practice of therapy can help improve language function. Second, even though meta-analytic reviews have found mixed results regarding the benefits of aphasia rehabilitation [8,31], results such as the present study contribute to the database of positive treatment outcomes after aphasia rehabilitation. Finally, based on our own previous work [32-36] where we have tracked patients' performance on weekly probes and have observed inter-session performance fluctuations, the present study provides a more detailed window into inter-session fluctuations (small scale fluctuations) that provide an important contrast to large scale fluctuations (second stroke) that may occur.

Conclusions

In this case study, we report a longitudinal profile of an individual with post-stroke aphasia, who received continuous rehabilitation through an iPad based therapy delivery platform. This person was provided with a tailored therapy program targeting language and cognitive functions that he practiced at home on a daily basis. During the course of his rehabilitation, however, he suffered a second stroke, which was detected by changes in performance on the therapy tasks. Subsequent to the second stroke, this individual resumed therapy practice and continued to make gains on language and cognitive functions. In some cases, therapy was restarted at lower levels and repeated through the various levels of difficulty; in other cases, new and more complex tasks were introduced as during the course of therapy. Tracking behavioral performance of individuals after a stroke is particularly important as it allows the ability to identify large fluctuations in the context of small/daily fluctuations therapy performance over a period of time.

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