So much technology, so little time: Factors affecting use of computer-based brain training games for cognitive rehabilitation following stroke

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ABSTRACT

Rehabilitation following stroke typically focuses on regaining use of the affected lower and upper limbs. Impairment of cognitive processes, however, is predictive of rehabilitation outcomes. Stroke survivors and their caregivers report difficulty finding time to practice gait and upper limb training at home due to the time demands of routine activities of daily living (ADL), leaving little time for cognitive retraining. Cognitive activities have become more readily accessible to the home user through web-based games that engage brain functions often disrupted by stroke. With neuropsychological testing, it is possible to "prescribe" brain training that targets the specific cognitive functions disrupted by an individual's acquired brain injury. We asked if computer-based braining training were made available in-home at no cost, would stroke survivors complete the training? Five stroke survivors participated, none completed the recommended 40 training sessions. Interviews with participants and caregivers reveal barriers to training including physical and cognitive limitations, as well as time and fatigue management. Training also showed effects on ADLs and mood.

1. INTRODUCTION

Rehabilitation following stroke routinely takes a bottom up approach, with primary focus placed on gait retraining (Putnam et al, 2006), followed by upper limb rehabilitation, and speech and language therapy. Impairment of higher order cognitive processes (comprehension, judgment, short-term verbal memory, abstract reasoning) however, predicts length of inpatient stay as well as number and frequency of referrals for outpatient and home therapies (Galski et al, 1993). Stroke patients and their caregivers frequently report difficulty finding time to practice gait and upper limb training in the home environment due to the increased time demands create by physical disability. Completing routine activities of daily living (ADL) with impaired upper and lower extremities can take much of the day. When appointments for outpatient therapy and medical follow-up are added to the day, patients and caregivers report little or no available time for self-initiated therapies, such as cognitive rehabilitation, despite the importance of cognitive processes in physical recovery.

Cognitive activities have become more readily available to the home user through the availability of web based brain training games that engage brain functions often disrupted by stroke. Computer based brain training is available for improving memory, attention, speed of information processing, mental flexibility and problem solving. Research has demonstrated that brain training can combat cognitive decline associated with the normal course of aging. In addition to improving performance on training tasks, the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study demonstrated training generalized to measures of real world function (Ball et al, 2002), and benefits were sustained for as much as five years after training time (Willis et al, 2006).

With appropriate neuropsychological testing, it is possible to "prescribe" brain training games that target thespecific cognitive functions disrupted by an individual's acquired brain injury. We initially invited community based stroke patients involved in outpatient neuro rehabilitation to participate in an interventional study that required adherence to a training schedule. Feedback from patients and their caregivers revealed little likelihood of compliance due to the time demands of ADLs and outpatient

therapies, consistent with Clay and Hopps (2003) findings of non-adherence to rigid regimens. The focus of this project was then shifted to examine factors affecting use of computer based brain training when the goal was defined (40 sessions of training, 15-30 minutes each) and the parameters regarding how the goal would be achieved were not. Lumosity (www.lumosity.com), a web based suite of brain training games grounded in neuroscience research, was selected for this single case series study. Lumos Labs, creator of Lumosity Games, offers a research portal which makes it possible to capture frequency, duration, and outcome of use at no cost to the participant. The brain training games target cognitive domains of function that are most often affected by stroke including memory, attention, processing speed, decision-making ability, and mental flexibility. Additionally, the Lumosity games are novel and engaging exercises in which the difficulty level continuously adapts to each individual's progress.

2. METHOD

2.1 Design

Participants were recruited from the clinical neuropsychology practice of Bonnie Connor, PhD. Each participant was asked to: 1) train on the Lumosity Basic Course (www.lumosity.com) suite of games as frequently as possible until 40 sessions were completed, 2) notice what factors interfered with training and 3) what factors made training easier. Participants agreed to complete a semi-structured interview when training was completed.

2.2 Participants

5 participants with right hemisphere stroke, ranging in age from age 63 to 73 years, participated in the study with the following inclusion criteria:

- Complete pre-training neuropsychological evaluation.
- Have access to a computer and the internet.
- Have adequate visual ability to view a computer screen.
- Have adequate motor ability to operate computer keys and use a mouse.
- Be willing to respond to semi-structured interview questions.

Table 1. *Characteristics of Participants.*

Participant	Sex	Age	Education (years)	Handed	Stroke (month/year)	Stroke Location	Depressed (GDS)
NB	F	63	16	R	12/2010	R-MCA	Mild
EB	M	73	19	R	12/2011	R-MCA	No
BF	M	66	14	L	05/2010 12/2008	R-Hemorrhagic	Mild
PP	M	67	14	R	11/2011	R-MCA	No
JW	F	65	12	R	06/2011	R-MCA	Mild

2.3 Neuropsychological Measures

Neuropsychological testing included measures of global cognition, verbal and visual memory, visuospatial skills, language functioning, and executive abilities including attention, processing speed, working memory and abstract reasoning. All measures were adapted from the University of California Medical Center, Memory and Aging Center's Bedside Screen, and used their age and education corrected normative database. Global cognition was measured with the Mini-Mental Status Exam (MMSE). The maximum score is 30 points. Scores above 25 are considered within normal limits (WNL) for the age range of these participants. Verbal memory following a 15-minute delay was measured with a 9-item list-learning task repeated over 4 learning trials. Visual memory was measured using a modified complex figure that was initially copied and, following a 15-minute delay, freely recalled and recognized in the presence of foils. Speed was measured with a phonemic fluency task in which as many words as possible beginning with a letter of the alphabet are generated in 1 minute, under constrained conditions (no proper names, no repeating a word by changing the ending). Attention to detail when copying a modified complex figure was used to measure attention. Problem solving was measured by design fluency, under

constrained conditions (5 rows of 7 boxes per row, each box containing 5 dots in the same location with the instruction to make a different design in each box by connecting dots with 4 straight line. Lines may intersect, not all dots have to be used).

Table 2. *Pre-Training Neuropsychological Testing Percentile Scores*.

Participant	Global Cognition (MMSE)	Memory (Verbal Delayed)	Memory (Visual Delayed Recall %; Recognized Y/N)	Speed (word fluency)	Attention (Complex Figure Copy)	Flexibility (Trail Making Modified)	Problem Solving (Design Fluency)
NB	WNL	30%	< 0.1% - N	21%	10%	< 0.1%	1%
EB	WNL	25%	19% - Y	18%	34%	50%	4%
BF	WNL	2%	< 0.1% - N	8%	< 0.1%	< 0.1%	0.1%
PP	WNL	30%	19% - Y	27%	0.4%	37%	50%
JW	WNL	30%	3% - N	53%	95%	32%	2%

2.3 Games

Lumosity, developed by Lumos Labs (www.lumosity.com), offers a set of web-based brain training games to improve cognitive function. The training is based on the volume of literature showing that behavior leads to structural and functional changes in the brain associated with specific task demands. Research has demonstrated that brain training can combat the cognitive decline associated with the normal course of aging. In addition to improving performance on training tasks, the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study demonstrated training generalized to measures of real world function (Ball et al, 2002), and benefits were sustained for as much as five years after training time (Willis et al, 2006). The Lumosity brain training programs focus on critical characteristics of effectiveness including: 1) targeting brain functions that will lead to the maximum benefit for users in daily life which involves transfer of improvement in the games to performance of real world tasks; 2) adaptivity based on setting training at a level that is challenging without being discouraging, and that adjusts task difficulty in response to individual user performance on a moment-to-moment dynamic basis, within task and across sessions; 3) novelty since working in new ways that are not over-learned is critical for driving nervous system remodeling; 4) engagement to keep the brain in an engaged and rewarded state, which makes it more receptive to learning and change, with rewards teaching the brain mechanism to process information more effectively; and 5) completeness by targeting a range of cognitive functions including processing speed, attention, memory, flexibility, and problem solving. Processing speed training uses spatial orientation and information processing tasks; attention training includes visual field and visual focus tasks, memory involves spatial recall, face-name recall (Figure 1), and working memory tasks focused on symbols, rhyming words, and visual-spatial pattern location and memory; flexibility includes task switching, response inhibition, verbal fluency, and planning (mazes); and problem solving uses basic arithmetic functions (addition, subtraction, multiplication, and division), logical reasoning (Figure 2), and quantitative reasoning (Hardy & Scanlon, 2009).

Participants were provided with a unique user name and password for access to the Lumosity web site (www.lumosity) research portal. Participants, and their caregivers (where appropriate), were given visual and verbal instructions describing how to access the program. Each participant was instructed to play the games as often as possible to complete 40 sessions.

Figure 1. *Familiar Faces. This game involves the user working as a server in a seaside restaurant. Each visitor has a name and places an order. The server must remember the orders and customer's names to earn a large tip. The game exercises associative memory for verbal and visual information. As performance on the task improves, more characters and more complicated orders are presented. The user must remember names within session and from previous sessions. This screen shot appears courtesy of* [Hardy & Scanlon, 2009].

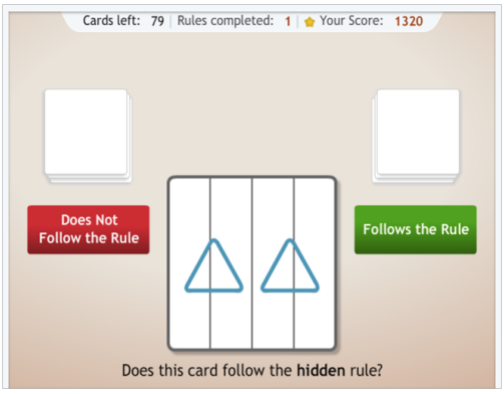

Figure 2. *By the Rules. Users must identify the hidden rule in a dynamic card game by indicating with each card which rule the card follows. In the example screen shot, the card might follow the rule if the rule were "blue," "triangle," "number 2,""vertical lines," or "solid border." If the user indicates the card follows a rule and it does not, then it must be another rule. However, if the user indicates it follows one of the aforementioned rules, and is correct, there are still 5 possible rules. Only through multiple tries is it possible to determine the rule. This game exercises mental flexibility and working memory, while using inductive and deductive reasoning. The user is challenged to formulate hypotheses about the current rule, and dynamically update their hypotheses as new information becomes available. This screen shot appears courtesy of* [Hardy & Scanlon, 2009].

2.4 Semi-Structured Interview Questions

Participants and caregivers were asked to respond to the following questions: 1) what problems did you experience during the study, 2) what was difficult about the training, 3) what was easy about the training, 4) were there problems with the software either with a) setting it up or b) the games themselves, 5) what were the best times of day to play, 6) on the days you did not play the games, why not, 7) have any activities of daily living (ADL) improved as a result of playing the games, and 8) would you purchase a Lumosity www.lumosity.com) subscription to continue training once the research protocol is completed.

2.4 Analysis

Pre/post training quantitative analysis was not possible as no participant completed the training. Thematic analysis (Braun & Clarke, 2006) was used to analyze the semi-structured interview data. Telephone interviews were conducted with all 5 participants, and 2 of their caregivers. Interview responses were transcribed, coded relative to the research questions, and analyzed using a theoretical thematic analysis.

3. Results

Semi-structured interviews were completed with each of the 5 participants, and 2 of their caregivers, between 28 and 29 June 2012. Access to the Lumosity (www.lumosity.com) research portal revealed no participant had completed 40 sessions as of 29 June 2012. Two participants (NB, EB) had Lumosity subscriptions, which they had used for several sessions prior to the research project. Total sessions completed by participants: NB – 13, EB – 0, BF – 14, PP – 14, JW – 1.

3.1 Barriers to use

Three themes emerged when examining overall problems with the training: physical limitations, cognitive limitations, and time and fatigue management.

3.1.1 *Physical limitations* including hemiplegia, hemianopsia, and color blindness contributed to problems with training. Some of the games require using the up, down, left, and right arrow keys, while other games required use of the alpha keyboard to type words. Four of the five participants have left hemiplegia resulting in only one hand being usable for manipulating the keyboard. JW said, "I can only use the right hand." NB said, "The biggest frustration is not using both hands for typing." PP said, "I only have one hand to type with. Anything involving the keyboard is difficult because of 'hunt and peck'" One of the participants (BF) is left-handed, has left hemiplegia, and also has visual field deficits as a result of hemianopsia. He is unable to play any of the games without the assistance of his caregiver. One participant (PP) is color-blind and found it "really frustrating to get the color games."

3.1.2 Cognitive limitations contributed to game play in several ways.

- *Log in.* Each of the five participants had difficulty accessing the online games without assistance. Lack of computer skills was a frequent comment, including not knowing how to login. "I'm technologically challenged. I would need Carrie (wife) to find the password and access the account" (EB). JW said, "I couldn't remember how to login. I get a little hyperventilating on the computer. I'm not so good on computers. I have performance anxiety." She had completed only one session at the time of the interview. She required her husband's assistance to login and did not want to bother either him or the researcher for assistance. During the telephone interview, we attempted to login. It was evident from this experience that the computer was not allowing her to go directly to the Lumosity web site. She was also getting numerous prompts that she did not understand how to respond to, including passwords kept in the 'keychain' that were inaccurate due to typing errors on her part.
- *Comprehension.* One participant (EB) misunderstood the training instructions to mean he was to continue playing games using his subscription rather than the research portal. Comprehension and information processing also contributed to other difficulties. BF is both physically and cognitively unable to access the internet on the home computer, start the program, or respond to some tasks without assistance. BF's caregiver (wife) said he had trouble "getting the directions for what he is supposed to do, and then following through fast enough to do the game."
- *Lack of awareness of deficits.* Scores on the depression inventory revealed each of the participants was either not depressed at all, or only mildly depressed despite significant physical and cognitive limitations. One participant (NB) stated, "I don't feel I have any problems" despite her caregiver (husband) indicating she was not able to login without assistance.

3.1.3 Time and fatigue management, especially fatigue management, was a consistent theme with each participant. Most participants said they preferred to play in the afternoon because "the morning routine interrupts" (NB). BF's caregiver (wife) said, "if we have activities away from the house, when we get home he is tired and can't sit down at the computer. After attending to the daily routine of blood pressure, pills, and hygiene it takes 15 minutes to get out of the house and into the car (due BF's mobility difficulties). A one hour appointment takes up the whole day." EB said he was trying to do the program when 'fresh.' Ideally he wanted to do it "first thing in the morning and I have a lot to do then," and even later in the day "I'm still tired." On days when participants did not train the consistent response related to too little time and fatigue. JW said, "I get busy with life." EB said he was "busy doing a bunch of other things. I'm on 4 boards (non-profit organizations)." PP said, "Probably because I've had a lot of other things going on, circumstances out of my control." BF's wife said 4 days a week he cannot do the training due to outside activities including 2 days a week of physical therapy. "Outside activities use up (BF's) energy reserves, he can't do it." NB's husband said, "Some days she's very tired."

3.1.4 Problems with software. Problems with the games were related to the physical and cognitive limitations of the participants. "Not being able to get out of a game that is too difficult" was a problem for BF. His hemianopsia and left visuospatial neglect were also a problem with screen navigation. After scanning

the whole screen, BF's wife said he "disregards what he saw on the left." Visual scanning was a problem for other participants, as well. EB said, "the 'bird game' was OK until they added the distractions." Most participants stated word games that required using the entire keyboard presented problems. "Word games don't allow enough time to 'hunt and peck'" (BF's wife). Cognitive problems with the word games related to individual limitations with generativity. JW said, "If I could run and get my dictionary" and EB said, "I had trouble coming up with more words." Navigating quickly enough with the mouse was also a problem. EB reported problems with "hand-eye coordination." PP said, "When I move the cursor to 'how to play' I would get a bunch of screens."

3.2 Facilitators of use

- *Short duration of training sessions.* Each training session lasts 15-30 minutes. The feature most frequently cited as a facilitator of use was this short duration of sessions. PP found "the short time to get in and out of a program" made it possible for him to play more than once a day. "If I have a spare moment I sit down and do it." BF's wife said, "The length of the program is a good length."
- *Problem Solving.* Most participants found the basic arithmetic problems easy. EB said, "I could do the problems" and JW said, "I liked those." Others found the logical reasoning tasks to be "user friendly" (BF's wife), "it is a concept he can work with."
- *Game Playing Experience.* Experience with the games also made doing them easier. PP said, "Once I started getting interested it got a lot easier. A lot was very interesting. I'm discovering speed bumps in my head."

3.3 Improvement in Activities of Daily Living

Participants generally found the training to improve memory, speed of information processing, problem solving, and visual scanning. Mood was also affected by training. Caregivers reported modest improvements in daily functioning.

- *Memory.* NB reported she could "remember words better. I used to loose names of plants, now not so much." EB reported the facial recognition has "gotten me more in tune with paying attention to names, which I've always been terrible at."
- *Problem Solving.* PP noted in his daily life, "When I see I'm making a mistake, I don't continue doing it. I developed strategies to offset my personal difficulties."
- *Visual Scanning.* NB said "when I do 'Bird Watching' a lot I can notice things in my peripheral vision very quickly." While her husband observed that changes he has noticed are "small," he said, "she is reading a lot better." In the past she would "pass over chapters" and now she does not.
- *Mood.* Two of the 3 participants who have completed more than 2 training sessions found training to improve their mood. NB's husband said when she is "down, depressed or angry and does Lumosity she feels better." NB reported the "success factor improves my mood." PP also noticed improved mood. JW, who has completed 1 session said, "I don't know what made me feel sharper, quicker in my brain. I like doing it." In contrast, BF, who has profound physical, visual, and cognitive deficits, finds most of the games frustrating because he is unable to do them, and is unable to quit out of games that are too difficult.

3.5 Would you buy a subscription? The 2 participants who already have subscriptions would continue their subscriptions. The remaining 3 participants cited financial limitations to purchasing a subscription. PP said, "If money was not an issue I'd do it." JW and BF's wife cited fixed incomes with expenses going up and income going down to be limiting factors. BF's wife said, "We would have to commit to a 3-year subscription to make it affordable. A 1-year subscription is too expensive."

4. DISCUSSION

Qualitative data suggest, when left to decide when and how often to play brain training games to improve cognitive functioning, stroke survivors have difficulty finding the time, and are often physically and cognitively challenged by task demands beginning with the login process. In the absence of a trainer or 'coach,' participants had difficulty initiating training, and persisting with training in the presence of physical and cognitive challenges. Once training is initiated and pursued, however, the process becomes easier and the benefits are more apparent. Despite Clay and Hopps (2003) findings of non-adherence to rigid regimens, participants in this study found it difficult to establish routines of their own that would facilitate a consistent, predictable, reliable training regimen. As a consequence, no participant completed the recommended 40 sessions of training. It is notable that the one participant who overcame the

computer problem of frequently getting "multiple screens" during training, also wanted to train whenever possible once he developed some facility with the program. Participants in this study will be followed through completion of 40 sessions of training, after which post-training measures of neuropsychological functioning, self-reported competency, as well as semi-structured interview results will be obtained and reported.

For commercial products, such as Lumosity, to be viable for patients with physical and cognitive limitations, it will be important for game features to include: 1) allowing adequate time for visual scanning of the video display and responding to stimuli in the presence of problems with visual scanning and visuospatial neglect, 2) adequate time for navigating the keyboard one-handed, and 3) the ability to quit out of games that are beyond the participant's abilities. Additionally, establishing a pricing structure that takes into account the financial limitations of older adults on fixed incomes will be important.

5. CONCLUSIONS

The initial results from the 5 participants in this study reveal the difficulties stroke survivors experience on a day to day basis with managing the fundamental activities of daily living, before supplemental activities can be added to their schedule. While each of the participants was interested in brain training games, designing a product that is commercially viable for a wide ranging audience is difficult. The task demands of training suitable for an older adult who has experienced a stroke leading to physical and cognitive deficits are very different from training suitable for a young adult seeking to maximize their cognitive functioning. The availability of web based training for cognitive recovery following brain injury offers tremendous potential for in-home, on-demand rehabilitation.

Acknowledgements: This research was supported by Lumos Labs, 153 Kearny Street, San Francisco, CA, 94108.

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