Case study series using brain-training games to treat attention and memory following brain injury

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ABSTRACT

Rehabilitation following acquired brain injury typically focuses on regaining use of the affected lower and upper limbs. Impairment of cognitive processes, however, is predictive of rehabilitation outcomes. Cognitive activities have become more readily accessible to the home user through web-based games that engage brain functions often disrupted by acquired brain injury. With cognitive testing, it is possible to "prescribe" brain training that targets the specific cognitive functions disrupted by an individual's acquired brain injury. Previous research has shown that individuals with acquired brain injury have difficulty finding the time to train on cognitive tasks at home, and are often confused and overwhelmed when attempting to operate computers without assistance. We asked if computer-based braining training were made available in a structured training format, at no cost to the participant, would acquired brain injury survivors benefit from using commercially available brain training? Three acquired brain injury patients were recruited. Pre and post training psychometric measures of memory and attention were obtained, as well as qualitative evaluation of the user experience.

1. INTRODUCTION

Rehabilitation following acquired brain injury such as 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 (sustained and divided attention, short-term verbal and visual memory, abstract reasoning, comprehension, and judgment) however, predicts length of inpatient stay as well as the number and frequency of referrals for outpatient and home therapies (Galski et al, 1993). Cicerone et al. (2010) found remediation of attention deficits after TBI should include direct attention training and metacognitive training to promote development of compensatory strategies and to foster generalization to real world tasks. This meta-analysis found direct attention training through repeated practice using computer-based interventions might be considered as an adjunct to treatment when there is therapist involvement. Regarding memory training, the task force continued to recommend training in the use of external compensations (including assistive technology) with direct application to functional activities for persons with moderate or severe memory impairment after TBI or stroke

Cognitive activities have become more readily available to the community dwelling user through the availability of web based brain training games that engage brain functions often disrupted by acquired brain injury. 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).

The ACTIVE study started a revolution in computer-based brain training games for normal individuals. Computer-assisted training for brain injury had been available since the 1970's (Lynch 2002). While the initial application of video games was for therapeutic recreation, by the mid-1980s, the IBM PC and Macintosh were available and clinicians began to develop rehabilitation applications for cognitive retraining following traumatic brain injury, which showed positive results in areas such as attention training (Shaw and McKenna, 1989, Park and Ingles 2001). It was only after research demonstrated that brain training could stem the tide of age-related cognitive decline that "brain fitness" became the focus of computer-based brain training. Currently there is a range of commercially available brain training games for normal adults to use to improve or maintain cognitive function. In contrast to programs designed for patient populations, these commercially available brain-training games are priced to be accessible to the general public. The pricing structure and commercial availability of these programs makes them more accessible to patient populations. There is a growing body of research using commercially available brain training games to treat acquired brain injury (Zickefoose, et al., 2013, Kessler et al., 2013, Finn & McDonald, 2011). This study examines the therapeutic value for individuals with acquired brain injury of computer-based brain training designed for normal adults, in combination with metacognitive training.

Lumosity (www.lumosity.com), a web based suite of brain training games grounded in the neuroscience of brain plasticity, was selected for this single case series study. Decades of research in brain plasticity, the ability of the brain to remodel itself in response to changes in sensory inputs, has demonstrated the capacity for intact areas of the brain to take over for damaged areas (Jenkins and Merzenich 1987, Pascuale-Leone and Torres 1993, Buonomano and Merzenich 1998, Hallett 1999, Johansson 2000, Harvey 2009). The damaged areas may also be capable of recovering some of their lost function (Cramer et al. 2011). Research has demonstrated that gray matter, the neuronal cell bodies and supporting structures in the brain, can thicken in response to us or shrink due to lack of use—"use it or lose it" is a fundamental principle of brain function. Neural connections can be created and honed through practice or can deteriorate and disappear when not used. When the physical brain changes due to acquired brain injury, cognitive abilities change—most often for worse, not better. Neuroplasticity research has demonstrated the brain's ability to sharpen degraded sensory inputs and revitalize function (Pascual-Leone and Torres 1993, Tallal et al. 1996, Erickson et al. 2007, Berry et al. 2009, Dux et al. 2009).

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 acquired brain injury 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.

The aim of this study was to examine the ability of community dwelling patient's with acquired brain injury to use and benefit from commercially available computer-based brain training games designed for unimpaired adults. We were particularly interested in each individual's ability to improve visual attention and memory using computer-based brain training in combination with metacognitive training, and the effects of these improvements on function in daily life.

2. METHOD

2.1 Design

This study utilizes a single case A-B-A design (i.e. pre-testing, intervention phase, post-testing) in the context of an outpatient treatment setting. All testing in the treatment setting was administered once at baseline and once following completion of training. Each participant was his or her own control. Participants received 24 sessions of training on Lumosity during group speech therapy. Participants were encouraged to train on Lumosity games outside of their speech therapy sessions.

Patients came to the outpatient NeuroRehab Department at Sierra Nevada Memorial Hospital two times per week for 60 minutes for a total of 12 weeks. Each training session included 15 minutes of metacognitive training by the speech therapist to promote development of compensatory strategies and foster generalization to real world tasks, followed by group discussion for psychosocial support. Each session included 15-20 minutes of Lumosity Training Program games, and 15-20 minutes of free play on any Lumosity games selected by each individual. Training took place in a group setting. Patients trained on either a computer or tablet using the Lumosity web site games for attention and memory. Lumosity

Brain Performance Test subtests (BPT) were completed pre/post. These are computer-based tests modeled on standardized neuropsychological test that produce a composite score. Following completion of training the semi-structured interview was conducted with each patient.

2.2 Participants

Patients were recruited for the study from individuals with acquired brain injury who were receiving out patient speech therapy at Sierra Nevada Memorial Hospital. Patients included in the case series met the following criteria: 1) adult over age 18, 2) with acquired brain injury, 3) receiving out patient speech therapy services from Sierra Nevada Memorial Hospital, 4) with adequate vision (corrected or uncorrected) to see a standard computer or tablet screen, 5) with adequate upper extremity mobility to use a computer or tablet keyboard, 6) ability to use a computer or tablet 45-60 minutes 2 times per week for 12 weeks (no prior computer experience required), and 7) willing to respond to semi-structured interview questions. Each patient gave informed consent to participate in the study. Dignity Health Institutional Review Board waiver was obtained to present anonymized case study results.

Patients were excluded who: 1) had compromised cognitive ability such that they were unable to comprehend instructions regarding computer or tablet use, or were unable to comprehend training instruction, 2) were physically unable to view computer or tablet screen for up to 60 minutes 2 times per week for 12 weeks, 3) were physically unable to use a computer or tablet keyboard, 4) were unable to commit to training 2 times per week, 60 minutes per session, for 12 weeks.

Three individuals completed the program. Patient A is a 34-year-old male high school graduate with some college coursework who worked in a military skilled occupation. He fell 13 feet while at work in May 2013, landing on the back of his head. He suffered a traumatic brain injury with brief loss of consciousness that resulted in headaches, blurred vision, and difficulty with attention and concentration. He has returned to work less than full time on modified duty. Patient B is a 60-year-old male high school graduate who completed 3 to 4 years of trade school and was self-employed in a skilled occupation. He was in a motor vehicle accident in 2008 in which he suffered a severe traumatic brain injury, as well as multiple bone fractures. He continues to have problems with memory and attention. He has not returned to work. Patient C is a 66-year-old female with 16 years of education who worked in a professional occupation. She had surgery in July 2012 to remove a brain malformation that was causing seizures. The surgery removed her left hippocampus. She has not worked since the surgery. She has memory problems with acquiring new learning.

2.3 Neuropsychological Measures

Neuropsychological testing included Woodcock Johnson Cognitive Abilities (WJ III) subtests Pair Cancellation, Verbal-Auditory Learning Immediate and Delayed, and Lumosity Brain Performance Test (BPI) 7 Subtest Composite score. Pre and post training performance was evaluated in the areas of: 1) psychosocial functioning using the Barkley Functional Impairment Scale (BFIS-Self and Other Report, 2011), 2) visual attention using the Woodcock Johnson Tests of Cognitive Abilities (Woodcock et al., 2001) Pair Cancellation subtest, 3) visual memory using the Woodcock Johnson Tests of Cognitive Abilities Verbal-Auditory Learning and Delayed subtests, 4) composite computer-based brain training overall cognitive performance using a composite score of 7 subtests from the Brain Performance Test (BPT) in the Lumosity (www.lumosity.com) program.

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

Participant	WJ-III Verbal-Auditory Learning	WJ-III Verbal-Auditory Delayed	WJ-III Pair Cancellation	Lumosity Brain Performance Test (BPT)
A	50%	14%	18%	45%
B	7%	8%	23%	10%
C	21%	7%	49%	16%

2.4 Intervention Materials

2.4.1 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. 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 (Figure 1), memory involves spatial recall, *n*-back recall (Figure 2), 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, and quantitative reasoning (Hardy & Scanlon, 2009).

Figure 1. *Lost in Migration. This game challenges attention and response inhibition. The game is used for avoiding distraction, increasing work productivity, and improving concentration. This screen shot appears courtesy of Lumosity.*

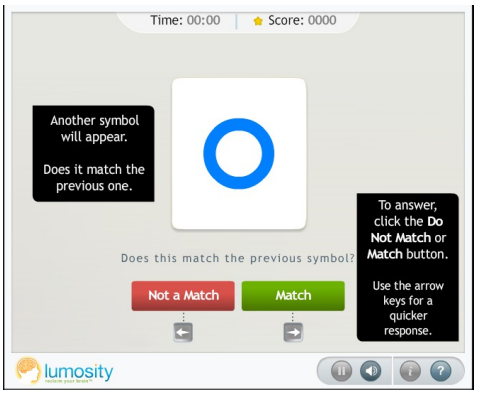

Figure 2. *Speed Match. This game challenges processing speed and reaction time. It is based on the n-back task. Speed training is designed to improve the ability to think quickly, accurately, and pay attention while others are talking. This screen shot appears courtesy of Lumosity.*

Participants were provided with a unique user name and password for access to the Lumosity web site (www.lumosity) research portal. Participants trained on Lumosity games two times per week for 30 to 40

minutes per session in the NeuroRehab Lab. Each participant also had access to the Lumosity games outside the structured twice-weekly training sessions. Each participant was invited to play the games as often as possible. All participants completed the 24-class session training in the NeuroRehab Lab.

2.4.2 Metacognitive Training and Psychosocial Support Metacognitive training included 1) memory compensation techniques, 2) types of memory, use of checklists, and routines, 3) strategies to reduce unwanted auditory, visual, and anxiety related distractions, 4) strategies to maximize depth of understanding for new material and optimize learning, 5) compensatory strategies to reinforce recall at the community level including note taking tools, session agendas, and handouts. Psychosocial training included 1) symptom management and coping strategies for headache, frustration, dizziness, feeling overwhelmed, 2) sharing among participants compensations and strategies for symptoms, 3) recognizing strengths and weakness about specific injury, learning about mechanism of injury, and how that translates into cognitive and emotional issues, 4) checking in about concerns, likes and dislikes, and 5) expressing frustrations with the games.

2.5 Semi-Structured Interview Questions

Following completion of the 24 session training, participants were asked to respond to the following questions: 1) what was your overall impression of the cognitive computer games, 2), what did you enjoy about working with computer cognitive games, 3) what were the challenges involved in training, 4) how has the training affected your day to day life?

2.6 Analysis

Pre/post training quantitative analysis is graphically displayed. Thematic analysis (Braun & Clarke, 2006) was used to analyze the semi-structured interview data. Video interviews were conducted with all 3 participants.

3. Results

3.1 Quantitative Results

Age-related percentile scores pre and post training are displayed graphically for each participant. All participants experienced improvement on Woodcock-Johnson III outcomes measures with the exception of Woodcock-Johnson III Pair Cancellation. *Participant A* showed decline in the BPT composite score following Training. The Barkley Functional Impairment Scale (BFIS) was used as a self- and other-report measure of the impact of acquired brain injury on instrumental activities of daily living. This instrument did not produce reliable data in the overall analysis. One participant did not have a collateral that knew her well and she misunderstood the instructions regarding pre-injury assessment of her functional abilities. Neither the participants, nor their collaterals, rated composite functional abilities in the impaired range post injury; therefore pre/post training scores were uninformative.

3.1.1 Participant A showed improvement on all outcomes measures with the exception of WJ-III Pair Cancellation and Lumosity Brain Performance Test.

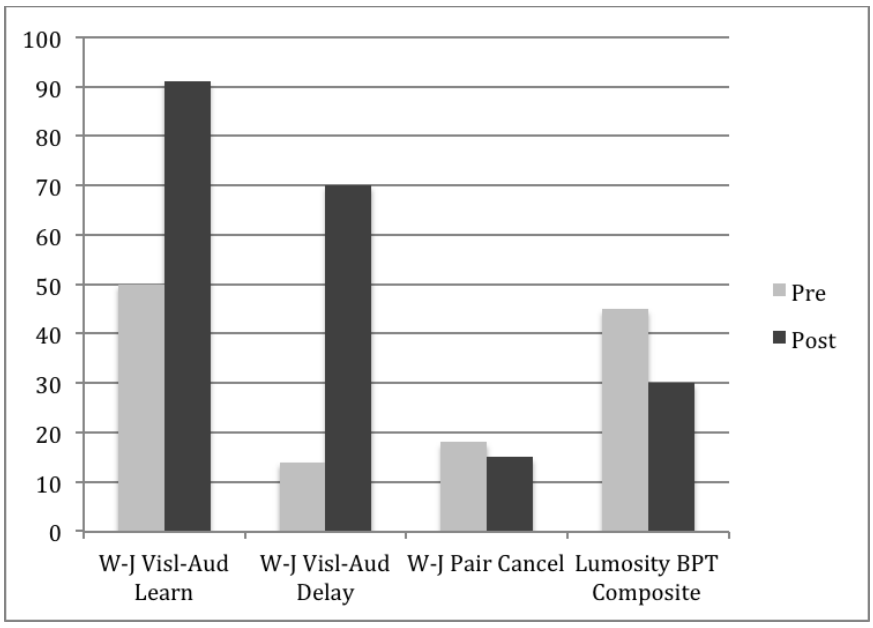

Figure 3. *Participant A's pre and post training performance expressed in age-related percentile scores on the Woodcock-Johnson III Tests of Cognitive Abilities Visual-Auditory Learning, Visual-Auditory Delayed, Pair Cancellation, and Lumosity's Brain Performance Test.*

3.1.2 Participant B showed modest improvement on all outcomes measures.

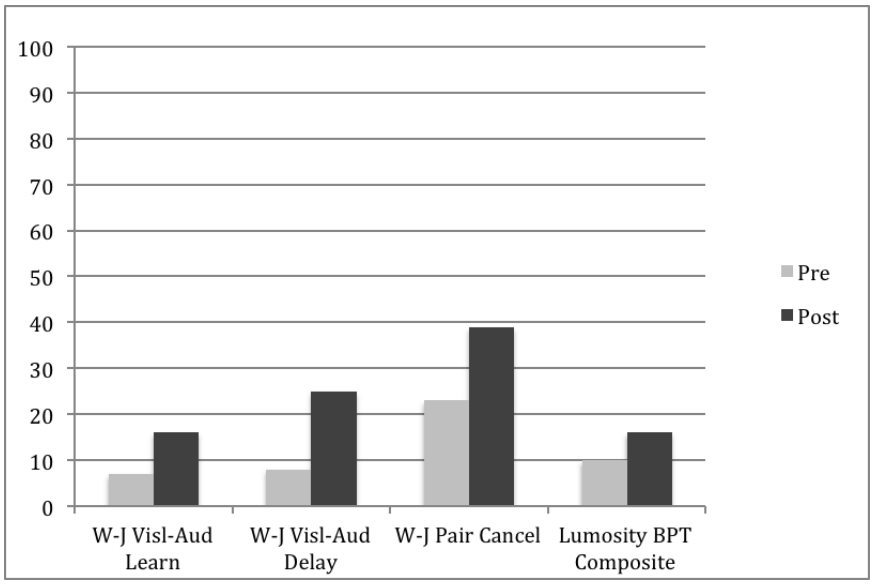

Figure 4. *Participant B's pre and post training performance expressed in age-related percentile scores on the Woodcock-Johnson III Tests of Cognitive Abilities Visual-Auditory Learning, Visual-Auditory Delayed, Pair Cancellation, and Lumosity's Brain Performance Test.*

3.1.3 Participant C showed modest improvement on all outcomes measures with the exception of W-J III Pair Cancellation.

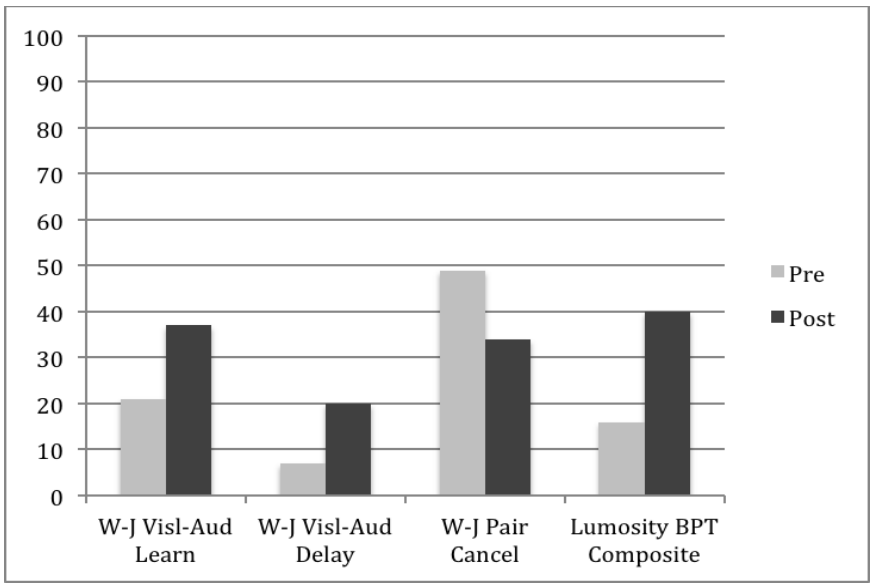

Figure 5. *Participant C's pre and post training performance expressed in age-related percentile scores on the Woodcock-Johnson III Tests of Cognitive Abilities Visual-Auditory Learning, Visual-Auditory Delayed, Pair Cancellation, and Lumosity's Brain Performance Test.*

3.2 Qualitative Analysis

Semi-structured interviews were completed with each of the 3 participants following completion of 24 sessions in the NeuroRehab Computer Lab. Participants were asked to give an overall impression of the cognitive computer games, what they enjoyed about working with computer cognitive games, what were the challenges, and how did the training affect day to day life. Three themes emerged when examining participation: brain engagement, remembering to remember, and cognitive processing efficiency.

3.2.1 Brain Engagement

Participant A found the game training improved critical thinking skills. When allowed to engage in 'free play,' he trained on games that improved his spelling skills important for his work. He enjoyed the opportunity to "exercise" his mind, however found the training games to be repetitive and wanted more variety. He questioned whether his scores on the computer games got better "because my brain got better or I simply got better at the game." *Participant B* found the games were engaging and offered him "new things to help out" his brain function. He described some games as "fun" and enjoyable. *Participant C* found the games "engaged me, pulled me into something helping my brain." She looked forward to game play and to receiving feedback about her game performance.

3.2.2 *Remembering to Remember*

Participant A found the comprehensive training program helped him develop strategies to compensate for attention and memory problems following brain injury, and facilitated his ability to remember to remember information important in his daily life. *Participant B* reported being able to "remember things better." "Things are coming back to me quicker, better—I'm remembering things better." He is remembering to focus on memory in his day-to-day life. *Participant C* reported the game play gave her confidence that her "memory is improving." She described the game training as getting her "into the flow of using my memory." She expressed the opinion that her memory was being helped in "a subtle way" as a result of game play.

3.2.3 Cognitive Processing Efficiency

Participant A found computer-based brain training improved the speed and efficiency with which he processes new information. *Participant B* found cognitive processing efficiency was diminished by spending too long on the computer or playing games that were too challenging, which led to headaches. *Participant C's* impression was that her "mental flexibility" and "thinking" were improving as a result of computer-based brain training.

4. DISCUSSION

All participants completed the 24 sessions of training in a supervised treatment setting. Unlike participants post acquired brain injury who were unable to complete training in their own homes (Connor and Standen, 2012), these individuals benefited from a structured environment that included a regular schedule of training, metacognitive training by the speech therapist to promote development of compensatory strategies and foster generalization to real world tasks, followed by group discussion, and supervision when using computers to access brain training games. Quantitative data analysis revealed that 2 of the 3 participants experienced modest improvement on the objective outcomes measures examining memory and attention. One participant (Participant A) experienced substantial gains on outcomes measures of memory and composite cognitive functioning, without improvement on outcomes measures of attention. The individual who experienced the greatest gains was the youngest individual with the most recent injury. This individual's improvement may be partially related to the natural recovery process; however, he clearly articulated strategies he learned over the course of training that improved the efficiency and effectiveness of his memory and attention. Each of the participants enjoyed the opportunity to engage their brains in purposeful activity, which was subjectively beneficial. Despite Clay and Hopps (2003) findings of non-adherence to rigid regimens, participants in this study found the routine of twice weekly training sessions to be beneficial and effective.

These participants experienced intermittent technical difficulties when attempting to train outside the twice-weekly program suggesting that a usability gap exists between computer-based brain training and individuals with brain injury. 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, 2) adequate time for navigating the keyboard to allow for cognitive and physical limitations, and 3) the ability to terminate games that are beyond the participant's abilities and move on to other games. Establishing a pricing structure that takes into account the financial limitations of individuals on fixed incomes will be important.

5. CONCLUSIONS

Rehabilitation research conducted in treatment settings poses challenges unlike those of grant-supported research conducted by academics and professional researchers. Self- or unit-directed research is limited by insurance reimbursements, lack of clinician time, and self- or unit-directed research may not be generalizable to other patients (Wilson & McLelland, 1997). Nevertheless, without the knowledge provided by such research, it is difficult to assess the effectiveness of clinical practice. The initial results from the 3 participants in this study reveal that individuals with acquired brain injury may need the structure and support of a professionally staffed and supported program to benefit from commercially available brain-training games, consistent with the findings of Cicerone et al. (2010). While each of the participants was interested and engaged in the brain training games, designing a product that is commercially viable for a wide ranging audience, including individuals with cognitive and physical limitations, is difficult. The task demands of training suitable for an adult with acquired brain injury involving physical and cognitive deficits are different from training suitable for a young adult seeking to maximize cognitive functioning. The availability of web based training for cognitive recovery following brain injury offers tremendous potential for cognitive rehabilitation, as long as the necessary supports are in place.

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6. REFERENCES

Ball, K, Berch, DB, Helmers, KF, Jobe, JB, Leveck, MD, Marsiske, M, Morris, JN, Rebok, GW, Smith, DM, Tennstedt, SL, Unverzagt, FW, & Willis, S (2002), Effects of cognitive training interventions with older adults: A randomized controlled trial. *JAMA*, **288**, 18, pp. 2271-2281.

Barkley, RA (2011), *Barkley Functional Impairment Scale (BFIS)*. New York, New York. The Guilford Press.

Berry, AS, Zanto, TP, Clapp, WC, Hardy, JL, Delahunt, PB, et al. (2010) The influence of perceptual training on working memory in older adults. *PLoS ONE.* 5(7): e11537. doi: 10.1371/journal.pone.0011537.

Braun, V & Clarke, V (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology,* **3**, 3, pp. 77-101.

Buonomano, DV, Merzenich, MM (1998). Cortical plasticity: from synapses to maps. *Annual Review of Neuroscience.* doi: 10.1146/annurev.neuro.21.1.149.

Cicerone, KD, Langenbahn, DM, Braden, C, Malec, JF, Kalmer, K, et al. (2010) Evidence-based cognitive rehabilitation: Updated review of the literature from 2003 through 2008. *Archives of Physical Medicine and Rehabilitation,* **92,** 4, pp. 519-530.

Clay DL, Hopps JA (2003), Treatment adherence in rehabilitation: The role of treatment accommodation. *Rehabilitation Psychology*, **48**, 3, pp. 215–219.

Connor, BB & Standen, PJ (2012). So much technology, so little time: Factors affecting use of computer-based brain training games for cognitive rehabilitation following stroke. The Ninth International Conference on Disability, Virtual Reality and Associated Technologies (ICDVRAT). Laval, France, 2012 Conference Proceedings.

Cramer, SC, Sur, M, Dobkin, BH, O'Brien, C, Sanger, TD, Trojanowski, JQ et al. (2011). Harnessing neuroplasticity for clinical applications. *Brain*, doi: 10.1093/brain/awr039.

Dux, PE, Tombu, MN, Harrison, S, Rogers, BP, Tong, F & Marois, R (2009). Training improves multitasking performance by increasing the speed of information processing in human prefrontal cortex. *Neuron,* **63**, 1, pp. 127-138.

Erickson, KI, Colcombe, SJ, Wadhwa, R, Bherer, L, Peterson, MS, Schalf, PE et al. (2007). Training-induced plasticity in older adults: Effects of training on hemispheric asymmetry. *Neurobiology of Aging,* **28**, 2, pp. 272-283.

Finn, M, & McDonald, S (2011). Computerised cognitive training for older persons with mild cognitive impairment: A pilot study using a randomised controlled trial design. Brain Impairment, **12**, 3, pp. 187–199.

Galski T, Bruno RL, Zorowitz, R, Walker J (1993), Predicting length of stay, functional outcome, and aftercare in the rehabilitation of stroke patients. The dominant role of higher-order cognition. *Stroke,* **24**, 12, pp. 1794-1800.

Hallett, M (1999). Review: plasticity in the human motor system. *Neuroscientist*. doi: 10.1177/107385849900500518.

Hardy, J & Scanlon, M (2009). The science behind lumosity. Lumos Labs. San Francisco. www.Lumosity.com.

Harvey, RL (2009). Improving poststroke recovery: neuroplasticity and task-oriented training. *Current Treatment Options in Cardiovascular Medicine*, **11**, 3, pp. 251-259.

Jenkins, WM & Merzenich, MM (1987). Reorganization of neocortical representations after brain injury: a neurophysiological model of the bases of recovery from stroke. *Progress in Brain Research.* **71**, pp. 249–266.

Johansson, BB (2000). Brain plasticity and stroke rehabilitation. *Stroke.* doi: 10.1161/01.STR.31.1.223.

Kesler, S, Hadi Hosseini, SM, Heckler, C. Janelsins, M, Palesh, O, et al. (2013). Cognitive training for improving executive function in chemotherapy-treated breast cancer survivors. Clinical Breast Cancer, **13**, 4, pp. 299-306. doi: 10.1016/j.clbc.2013.02.004.

Lynch, B (2002). Historical review of computer-assisted cognitive retraining. *Journal of Head Trauma Rehabilitation.* **17**, 5, pp. 446-57.

Mayas, J, Parmentier, FBR, Andres, P & Ballesteros, S (2014). Plasticity of attentional functions in older adults after non-action video game training: A randomized, controlled trial. PLoS One, 9(3):e92269.

Park, NW & Ingles, JL (2001). Effectiveness of attention rehabilitation after an acquired brain injury: A meta-analysis. *Neuropsychology*, **15**, 2, pp. 199-210.

Pascual-Leone, A & Torres, F (1993). Plasticity of the sensorimotor cortex representation of the reading finger in braille readers. *Brain.* doi: 10.1093/brain/116.1.39.

Putman K, De Wit L, Connell L et al (2006), Use of time by physiotherapists and occupational therapists in a stroke rehabilitation unit: A comparison between four European centres. *Disability and Rehabilitation*, **28**, 22, pp. 1417-1424.

Shaw, C & McKenna, K (1989). Microcomputer activities for attention training. *Cognitive Rehabitation,* January/February.

Tallal, P, Miller, SL, Bedi, G, Byma, G, Wang, X, Nagarajan, SS et al. (1996). Language comprehension in language-learning impaired children improved with acoustically modified speech. *Science*, **271**, 5245, pp. 81–84.

Willis, SL, Tennstedt, SL, Marsiske, M, Ball, K, Elias, J, Koepke, KM, Morris, JN, Rebok, GW, Unverzagt, FW, Stoddard, AM, & Wright, E (2006), Long-term effects of cognitive training on everyday functional outcomes in older adults. *JAMA*, **296**, 23, pp. 2805-2814.

Wilson, BA (1997). Research and evaluation in rehabilitation, In *Rehabilitation Studies Handbook* (BA Wilson & DL McLellan, Eds), Cambridge University Press, Cambridge, pp. 161-187.

Woodcock, RW, McGrew, KS, & Mather, N (2001). *Woodcock Johnson III Test of Cognitive Abilities.* Rolling Meadows, IL, Riverside Publishing.

Zickefoose, S, Hux, K, Brown, J, & Wulf, K (2013). Let the games begin: A preliminary study using *Attention Process Training-3* and *Lumosity* brain games to remediate attention deficits following traumatic brain injury. *Brain Inj*, **27***,* 6 *,* pp. 707-716*.*

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