Virtual anatomical interactivity: developing a future rehabilitation aid for survivors of Acquired Brain Injury

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ABSTRACT

Anatomically realistic virtual upper extremities with analogous true range of motion were developed and made available in a platform of video game-like exercises and tasks to pilot test re-learning to plan and execute purposeful motor control and related executive function in survivors of acquired brain injury. The platform game-play is designed for survivors disabled from using physical extremities due to brain injury and for other conditions of brain-motor malfunction. Survivors control virtual upper extremities (before being able to control physical extremities), in order to simulate on-screen physical exercises and task completions, i.e. they stimulate brain processes for pre-action planning and training. This paper describes several imagery (visualization) methods of virtual reality rehabilitation, reports on use of a virtual anatomical interactivity ("VAI") platform by twelve participant/survivors of acquired brain injury and suggests opportunities for expanded collaborative research.

1. INTRODUCTION

Therapies and rehabilitation for survivors of acquired brain injury ("ABI"), including traumatic brain injury, stroke, focal dystonias and other brain-motor malfunctions address chronic disabilities of millions of individuals.

It is suggested that there is an on-going need to augment conventional physical and virtual reality therapies and rehabilitation by using pre-action planning and training simulations with cost-effective telemedicine delivery systems (http://www.ncbi.nlm.nih.gov/pubmed/18633000). Virtual Anatomical Interactivity (VAI) may have an adjunctive role as a simple, inexpensive (using any laptop, tablet, personal computer, hand-held device and the like) method to stimulate the brain to re-learn pre-action planning for upper extremity motor control and related executive functions for performing purposeful activities of daily living. Further research and development is warranted.

2. USE OF IMAGERY IN VIRTUAL REALITY THERAPIES/REHABILITATION

The innate human capacity to image (visualize) physical movements has been used in several methods of therapy/rehabilitation: motor imagery; action-observation therapy; and mirror therapy.

Motor imagery has been defined as an "internal simulation of movements involving one's own body in the absence of overt execution" (Butler and Page, 2006). Motor imagery, action observation and mirror therapy have been used for upper extremity motor improvement or recovery following ABI (Butler and Page, 2006) or to decrease or eliminate phantom limb pain following amputation (Ramachandran and Hirstein, 1998). Studies of these methods have reported stimulation of the supplementary motor cortex, premotor cortex, primary motor cortex, parieto-frontal circuitry, temporal gyrus, and ipsilateral anterior lobe of the cerebellum (Butler and Page, 2006; Ramachandran and Hirstein, 1998; Lacourse et al, 2004; Vromen et al, 2011). Mental imagery and practice have shown improvements in upper-limb movement for both range of motion (ROM) and strength, as well as reaching and grasp during functional tasks for individuals four weeks post-stroke (Ramachandran and Hirstein, 1998). Other studies using fMRI found that during mental imagery and practice, plasticity is upregulated in the hemisphere opposite to the lesion for participants with stroke (Lacourse et al, 2004, Hong et al, 2012).

Individuals unaffected by ABI who played commercial video games (e.g. Super Mario, Tetris) were reported to experience, as a result of that game-play, volumetric cortical increases (Kuhn et al, 2013; Haier, 2009). Wii™ and Kinect™ have been used in physical and occupational therapies to improve motor control for patients capable of moving affected extremities (http://www.wiihabilitation.co.uk/?cat=13). In contrast, VAI, called

PreMotor Exercise Games ("PEGs"), is directed to survivors who cannot move extremities and therefore need to re-learn planning to move. PEGs provide more than imaginary feedback in that control of virtual extremities to simulate physical movements and accomplish virtual tasks instantly results in viewable, on-screen actions representing instantiations of each survivor's personal imageries/visualizations. In PEGs game-play, each survivor imagines a desired physical movement, controls one or more virtual extremities to simulate purposeful movement, and views the simulated activity in the virtual world as though it were actual activity in the real world (i.e. creating one's own virtual movement for physical movement mirroring by the affected extremity).

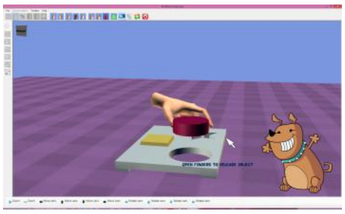
3. VAI PLATFORM USE BY TWELVE PARTICIPANT-SURVIVORS OF ABI

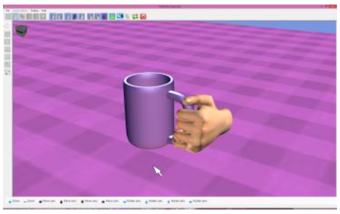
Twelve volunteer community program-based participant-survivors of ABI, in an institutional review board-approved study (report currently in press in a peer-reviewed journal), played only PEGs, no other video games (or physical or occupational therapy) during the study, averaging 20 minutes per session, three times each week for 20 weeks. Their average age was 53.9 years and the elapsed time post-injury was 11.4 years. Survivors' learning time for PEGs play averaged 5 minutes. Given that only volunteers participated, the few criteria included: being medically stable (examined by professional therapists supervising their daily activities); and presence of motor deficits determined by a Quick Functional Range ("QFR") and Strength Assessment. With an average elapsed time of 11.4 years post-injury, in some instances motor function disability remained unimproved post-intervention. Two baseline measurements were taken two weeks apart, before any PEGs intervention. Intervention outcome was a third measure. The tri-level measurement design was used to delineate intervention outcomes from participants' conditions at baselines one and two.

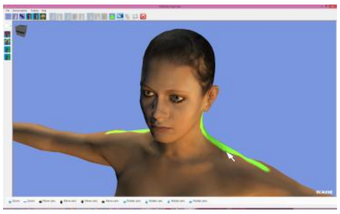
Virtual extremities are controlled by survivors' unaffected extremity or head movement via an input device, e.g. a standard computer mouse, touchscreen, or by webcam tracking head movements. Survivors point cursors to any or all parts of virtual fingers, hands, lower or upper arms, shoulders (right or left), and drag the part(s) to a new location and/or configuration. Survivors may execute virtual flexion/extension, supination/pronation, and abduction/adduction in any direction and at any angle. PEGs tasks for a virtual hand controlling virtual objects include: thumb and forefinger pincer movement to grasp a key; two finger movement to grasp a ball and drop it into a cup; multi-finger movement and action to pick up a spoon and drop it into a cup; full hand grasp around a mug handle; tapping movement and actions by index and middle fingers on a remote controller; and hand grasp of objects shaped as stars, circles, or squares then placement into correspondingly shaped slots. In addition, virtual movements may be directed by survivors to simulate real life tasks, such as: opening a designated correct box; with voice instructions to the survivor, selecting one box out of nine numbered boxes, screwing and unscrewing a light bulb, fitting pieces into a jigsaw puzzle, selecting numbers and executing arithmetic functions, and selecting letters to spell words. .

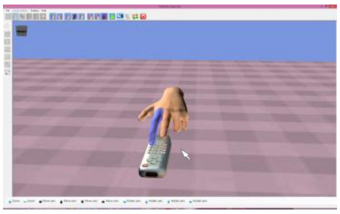
Measurements of motor skills improvements were made by: manual muscle testing using a goniometer to assess range of motion ("ROM"); a calibrated dynamometer to measure hand grip strength; and a pinch meter for testing strength for key, lateral and three-jaw chuck (tripod) grasps. Measurements of cognitive performance were made using the Executive Function Performance Test.

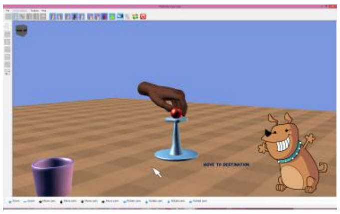
4. SELECTED SCREEN VIEWS

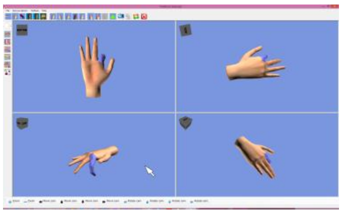












5. RESULTS

Chronic conditions of the participants were unchanged during the two week baseline period but improved, as noted below, after PEGs intervention. All results discussed below are post-intervention.

5.1 Shoulder Flexion/Strength

Shoulder flexion range of motion and strength were evaluated for nine participants, those having active shoulder movement. The normal range of motion for forward shoulder flexion is about 180°. For these participants, the mean ranges for improved shoulder movement were 99.9° to 126.3°, respectively. The nonparametric Friedman test for repeated measures ANOVA showed these differences to be statistically significant (p = 0.02). Participants no. 3 and no. 6 showed marked improvements ranging from trace to fair strength, while participants no. 8 and no. 11 showed improvements from fair to normal strength.

5.2 Wrist Flexion/Strength

The normal range of movement for wrist flexion is from about 60° to about 80°. Improvements were recorded in five participants, nos. 3, 6, 7, 10, and 11. For these five the range of movement improved from an average of 54° to an average of 67°. The difference was significant, as indicated by a nonparametric t-test (p = 0.04). Wrist strength remained generally stable for the participants, except for participant nos. 3, 6, and 8. These participants showed improvements in wrist strength from trace to poor, trace to fair, and good to normal, respectively.

5.3 Elbow Flexion/Strength

Elbow flexion range of movement and elbow strength were evaluated for the participants. The normal range of motion for elbow flexion is about 150°. Slight improvements were observed in participant no. 4 (5°), no. 11 (13°), and no. 12 (5°). The mean range of motion for these three participants increased slightly to 120.2°, 121.0°, and 131.5°, respectively. Participants no. 3, no. 6, and no. 8 showed improvements in elbow strength from trace to poor, trace to fair and good to normal, respectively.

5.4 Cognitive Skills

Cognitive skills of the participants were evaluated using the Executive Function Performance Test (“EFPT”) (Baum et al, 2008). The EFPT measures skills in initiation, organization, sequencing and safety. The EFPT tasks were cooking, taking medication, placing telephone calls, and paying bills. Activity demands of the EFPT included opening medicine bottles, reaching and using cooking tools, and using a calculator for paying bills. For overall EFPT task completion, ten participants performed at the level of complete independence following PEG intervention. The mean improvement in cognitive skills was statistically significant (p = 0.02). Nine participants demonstrated improvement in overall task performance. Improvement was noticeable in seven participants (nos. 1, 2, 3, 4, 6, 7, and 8). The mean difference on the global EFPT score was statistically significant (p = 0.02).

6. FUTURE STUDIES

Future VAI research questions related to survivors’ use of the VAI/PEGs platform include: 1) are cortical volumetric changes observed; 2) if so, which cortical areas are activated; 3) does manipulating virtual extremities activate different cortical areas than manipulating virtual extremities plus virtual objects to engage in virtual tasks; 4) how does 3), above, compare to cortical activity of unaffected individuals making actual physical movements or controlling virtual extremities; 5) compared to playing PEGs alone, do survivors’ motor recovery results differ if, in addition to controlling virtual affected extremities, survivors’ corresponding physical extremities are simultaneously stimulated by an applied device?

7. CONCLUSION

It is suggested that human imagery (visualization) and simulation (Ramachandran, 2011; Iacoboni, 1999) can be instantiated by survivors controlling virtual extremities to simulate physical movements and tasks and stimulate motor re-learning/planning. Survivors of ABI playing PEGs can instantly view feedback of such personally controlled movements and tasks. For re-learning planning for motor control and related executive function, PEGs should be further researched and developed in larger trials closer to the event of participants’ injuries as a future adjunctive therapy/rehabilitation.

8. REFERENCES

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