Exploration of computer games in rehabilitation for brain damage

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ABSTRACT

Cognitive and physical deficits are consequences of stroke/traumatic brain injuries (TBI). Without rehabilitation activity problems persist i.e. limitations to handle personal care, the work situation, and recreational activities. The aim of this study is to test an application of Virtual Reality (VR) technology with 3D computer games as an occupational therapy assessment/treatment method in rehabilitation for patients with cognitive and physical deficits. We also wanted to investigate if playing computer games resulted in improved cognitive function. An easy-to-use semi-immersive workbench with haptic game selection menu was located at an activity centre. The training activities were 3D computer games. Every time an activity was run, data about the hand movements were collected and analyzed. Quantitative variables were time (s) to perform the test, average velocity (m/s) and, tremor or uncertainty in movements HPR). Executive functioning was examined by utilizing Trial Making Test. The intervention involved five patients. Results provide evidence to support the use of 3D computer games in cognitive rehabilitation. As an implementation tool within the occupational therapy area, this technology seems to be well adapted to the technological and economical development of society in Sweden.

1. INTRODUCTION

Individuals who survive a severe stroke/ TBI (traumatic brain injury) face long-term problems with impairments, which create deficits in motor control and cognitive function. Without rehabilitation activity problems persist i.e. limitations to handle personal care, the work situation, and recreational activities. Occupational therapy aims to enable clients to engage in self-directed daily occupations in the areas of self-care/self-maintenance, school, work and leisure or play (American Occupational Therapy Association 1994). Thus, OT aims to promote recovery through purposeful activity; it encourages relearning through practice of functional tasks, with tasks gradually being made more difficult (Trombly *et al.* 2002). Relearning daily life activities often comprises intensive training, feedback and training in an environment that motivates the patient to train (Carr *et al.* 1996). If the focus is on these three aspects in rehabilitation, the design of activities should be attractive. When engaging people in occupation, the volition experience is an important factor. The term volition has been used to conceptualize motivation (Kielhofner *et al.* 1995). Kielhofner (1997) defines volition as “a system of dispositions and self-knowledge that predisposes and enables people to anticipate, choose, experience, and interpret occupational behavior”. Volition is concerned with what one holds important and finds enjoyable and satisfying. In order for stroke survivors to benefit from play or leisure participation, OTs must aim to find occupations that bring forth volition and discover ways to stimulate motivation (Chern *et al.* 1996). To create attractive activities it is important to understand the patient's subjective experience of the activity. Interventions that are productive, pleasurable and distracting can be efficient. Absorbing and interesting activities have a valuable effect on mood, health and recovery (Pierce 2001). The fact that an activity is pleasurable is important for motivating the patient. A well thought out mixture of the above mentioned aspects has the greatest probability for motivating the patient (Pierce 2001).

Employing computer games to enhance training motivation is an opportunity illustrated by the growing interest in the field of Serious Games (www.seriousgames.org). A serious game is a computer-based game with the goal of education and/or training in any form. This stands in contrast to traditional computer games, whose main purpose is to entertain. Serious games include games for learning, games for health and games for policy and social change. The health care sector is showing steadily increasing interest in serious games. Integrating gaming features into virtual environments has been reported to enhance motivation in adults undergoing physical and occupational therapy following a stroke (Jack *et al.* 2001; Kizony *et al.* 2005). According to Rizzo and Kim (2005), designers of rehabilitation tasks can benefit from enhancing motivation by leveraging gaming factors whilst presenting a patient with a repetitive series of cognitive or physical training challenges. Thus game play within an interactive and graphic-rich environment could support increased user engagement and consequently engagement in the rehabilitation process. The aim of this study is to test an application of VR technology with 3D computer games as an occupational assessment/treatment method in rehabilitation for patients with stroke/TBI with cognitive and motor deficits in an open rehabilitation centre.

2. MATERIAL AND METHODS

2.1 Participants

The study was carried out at an open rehabilitation centre in Uddevalla, Sweden. Five participants after stroke/TBI were recruited from that facility (Table 1); all participants were living in the community in their own homes.

Table 1. *Demographics for 5 participants in the study.*

Participants	Sex	Age (Years)	Etiology	Lesion site	Months since accidence
P1	M	60	Stroke	L	25
P2	M	48	TBI	R	68
P3	M	71	Stroke	R	9
P4	F	61	Stroke	R	9
P5	F	48	TBI	R	24

TBI: Traumatic Brain Injury, L: Left, R: Right.

2.2 Design

The intervention used a pre/post design. The intervention consisted of playing 3D-computer games during their rehabilitation period (2 times a week for 45 minutes for four weeks). The VR environment consisted of a semi-immersive workbench (fig. 1). The user observed a 3D image displayed above the tabletop using stereographic shuttered glasses. The user was able to reach into a virtual space and interact with 3-dimensional objects, using a haptic device (Phantom Omni, www.sensable.com). This created the illusion of manipulating virtual objects. A haptic game selection menu was designed, selecting various games with the haptic stylus from a game library (fig. 2).

2.3 Test procedures

2.3.1 Computer-based measurements (kinematics): we administered an upper extremity (UE) test developed in a previous study (Broeren *et al.* 2004; Broeren 2007). The task required the subject to perform reaching movements of the upper extremity (holding the haptic stylus), as dictated by the target placements. The targets appeared one after the other on the screen and disappeared when pointed at. The target placements (in all 32) in the 3D space were apparently random to the patients but were actually set according to a pre-determined kinematic scheme for evaluation purposes. Each assessment was composed of one trial during one session. Hand position data (haptic stylus end-point) were gathered during each trial. The x-, y- and z-coordinates, which were time stamped, gave the basic pattern of hand movement. After completion, the following registrations were examined; time (s) and distance (m). From this avg. velocity (m/s) and HPR (hand-path ratio – the quotient between actual hand trajectory and the straight-line distance between two targets) was calculated. Reference values for time (s), avg. velocity (m/s) and HPR were used from a previous study (Broeren *et al.* 2008).

Figure 1. *Semi-immersive workbench.*

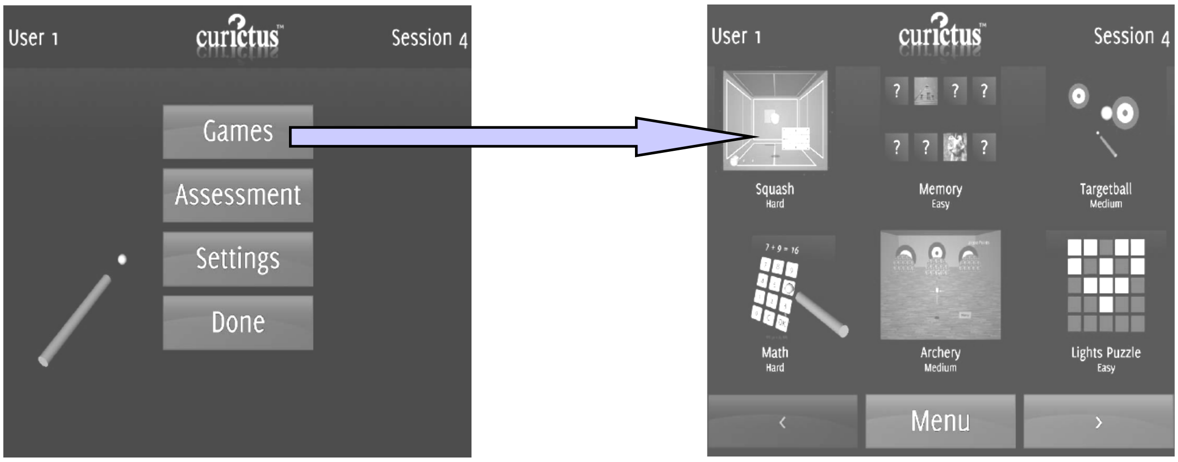

Figure 2. *Curictus user interface and haptic game selection menu.*

2.3.2 Executive function and attention. Trail Making Test, part A and B were used (Spreen and Strauss 1998). 1998). TMT assesses psychomotor speed and attention, and is regarded as a test of executive functioning. Part A requires drawing lines sequentially connecting 25 encircled numbers distributed on a sheet of paper and 25 and part B requires lines sequentially connecting encircled numbers and letters (e.g., 1, A, 2, B, 3, C, etc.). The time (s) taken to complete was used as the overall score.

3. RESULTS

3.1 Computer-based measurements (kinematics)

Time (s) was defined as the overall time to complete the UE test, executing movement to different targets in 3D-space. HPR reflects the coordination of these movements. A comparison between pre/post testing suggests that all participants decreased in the time parameter. An increase in avg. velocity (m/s) was found in four participants, P1, P3, P4 and P5. HPR decreased for P1, P2, P3 and P5. Three participants (P1, P3 and P4), time values were close to the reference values for time (s); 38.3s (SD: 12.5). For avg. velocity (m/s) none the participants came close to the reference value of 0.25 m/s (SD: 0.1). Three participants, P1, P2 and P5, HPR measure were within the range of the reference group value 2.1 (SD: 0.3).

Table 2. *Computer-based measurements for the participants.*

	Time (s)		Avg. Velocity (m/s)		HPR	
Reference values*	38.3s (SD: 12.5)		0.25 m/s (SD: 0.1)		2.1 (SD: 0.3)	
	Pre testing	Post testing	Pre testing	Post testing	Pre testing	Post testing
P1	88,62	54,24	0.12	0.21	2.31	1.88
P2	82,22	64,66	0.11	0.10	3.37	1.66
P3	67,80	54,21	0.17	0.20	2.59	2.51
P4	97,95	53,65	0.14	0.18	2.33	2.62
P5	120,38	67,09	0.14	0.19	3.31	1.99

* Reference values from a previous study (Broeren *et al.* 2008)

3.2 Executive function and attention

The raw scores for all participants are presented in Table 3. Scores achieved by P1, P3 and P5 for TMT A and B no longer differ from the normative sample (Spreen and Strauss 1998), indicating improvement. For P2 improvements were seen in TMT B and for P4 only in TMT A.

Table 3. *Performance time (in seconds) for participants on the Trail Making Trial, part A and B.*

		Pre testing	Post testing
P1	A	60	36*
	B	80	75*
P2	A	34	29
	B	84	52*
P3	A	58	45*
	B	345	180*
P4	A	60	24*
	B	65	45
P5	A	75	24*
	B	140	76*

* Improvements in relation to normative scores (Spreen and Strauss 1998).

4. DISCUSSION AND FUTURE WORK

At present the results of the study are tentative but the general experience of the VR application approach suggests that this intervention seems to be a promising tool in occupational therapy with a wide range of applicability. The limitations of the current study included the small sample size and the lack of other neuropsychological measures. A central component of this rehabilitation system is a library of engaging activities (games) that are simultaneously entertaining for the patient and beneficial for rehabilitation. Since patients have different impairments and abilities, a possibility to customize game play aspects is desirable. Currently, we have about a dozen games, no one fully designed and evaluated. In order to efficiently use computer games to train a particular function, we need to first determine what features a computer game should have to maximally benefit the skill in question. The game library is under construction and more games are to be developed and evaluated. However, game library construction for rehabilitation purposes is still an immature process. Applications should be developed with multidisciplinary collaboration and continuous user-centred input/evaluation methods. A major obstacle for this is the lack of models, methodologies and tools for VR system/content development (Rizzo and Kim 2005).

A brain damage may affect both motor and cognitive functions and the need for effective therapies and innovative rehabilitation is clear. Training with haptic devices has been suggested to enhance rehabilitation. Bardorfer and colleagues developed a method for evaluating the functional studies of the UE in subjects with neurological diseases (Bardorfer *et al.* 2001). The Rutgers group (Jack *et al.* 2001; Boian *et al.* 2002) developed a haptic interface called the "Rutgers Master II" force feedback glove. Conner *et al.* (2002) used an approach to rehabilitation of cognitive deficits following stroke using haptic guided errorless learning with an active force feedback joystick and computer. Baheux and colleagues (2006) developed a 3D haptic virtual reality system to diagnose visuospatial neglect. Kim *et al.* (2004, 2007) designed a VR system to assess and train right hemisphere stroke subjects. This study shows that the subjects made improvements in the kinematic variables measured with the haptic stylus (hand position data). Improvements were noted in time (s), avg. velocity (m/s), except P2, and HPR (except P4). Cognition is generally defined as the individual's ability to obtain and use information in order to adjust to environmental demands. TMT provides information on a number of factors, such as perceptual speed, attention, concentration, flexibility in sequencing, visual scanning, and visuomotor tracking (Tombaugh 2004)(Tombaugh 2004). The performance on the TMT improved and was within the normal range for almost all participants according to published norms (Spreen and Strauss 1998). Cognitive shifting and complex sequencing abilities, as measured by the TMT, appear to be important in determining instrumental activities of daily living (IADLs), regardless of the method used (Cahn-Weiner *et al.* 2002). Cognitive functions are important for the ability of the patient to gain from rehabilitation and to perform compensation. Playing computer games have the potential for therapeutic intervention of cognitive deficits. It can promote sustained attention, self-confidence and motivation of subjects during repetitive task training through multimodal immersive displays and interactive training programmes (Huang *et al.* 2006). The current findings are suggestive of further research in cognitive rehabilitation for the brain damage with this semi-immersive workbench (www.curictus.com).

5. CONCLUSION

It is possible that our results are due merely to an increase in task complexity when increasing level of difficulty in the computer games. Further research is needed to explore this issue. In addition, it is important to explore whether these findings generalize to activities of daily living. As an implementation tool within the occupational therapy area, this technology seems to be well adapted to the technological and economical development of society in Sweden.

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6. REFERENCES

American Occupational Therapy Association (1994), Uniform terminology for occupational therapy-third edition, *Am J Occup Ther,* **48**, *11*, pp. 1047-1054.

K Baheux, M Yoshizawa, K Seki and Y Handa (2006), Virtual reality pencil and paper tests for neglect: a protocol, *Cyberpsychol Behav,* **9**, *2* , pp. 192-195.

A Bardorfer, M Munih, A Zupan and A Primozic (2001), Upper limb motion analysis using haptic interface, *IEEE Transactions on Mechatronics* **6**, *3*, pp. 253-260.

R Boian, A Sharma, C Han, A Merians, G Burdea, S Adamovich, M Recce, M Tremaine and H Poizner (2002), Virtual reality-based post-stroke hand rehabilitation, *Stud Health Technol Inform,* **85**, pp. 64-70.

Broeren, J. (2007), *Virtual Rehabilitation – Implications for Persons with Stroke.* Institute of Neuroscience and Physiology, Rehabilitation Medicine and Institute of Biomedicine, Mednet – Medical Informatics, Göteborg University, Göteborg.

J Broeren, D Goude, L Claesson, K Sunnerhagen and M Rydmark (2008), Virtual Rehabilitation in an activity centre for community dwelling person with stroke; the possibilities of 3D computer games, *Cerebrovasc Dis.* In press.

J Broeren, M Rydmark and K S Sunnerhagen (2004), Virtual reality and haptics as a training device for movement rehabilitation after stroke: a single-case study, *Arch Phys Med Rehabil,* **85**, *8*, pp. 1247-1250.

D A Cahn-Weiner, P A Boyle and P F Malloy (2002), Tests of executive function predict instrumental activities of daily living in community-dwelling older individuals, *AppliedNeuropsychology,* **9**, *3*, pp. 187-191.

J Carr and R Shepherd (1996), *A Motor Relearning Programme for Stroke,* Butterworth – Heineman, Oxford.

J S Chern, G Kielhofner, C G de las Heras and L C Magalhaes (1996), The Volitional Questionnaire: psychometric development and practical use, *Am J Occup Ther,* **50**, *7*, pp. 516-525.

B B Conner, A M Wing, G Humphreys, R M Bracewell and D A Harvey (2002), Errorless learning using haptic guidance: research in cognitive rehabilitation following stroke, *Proc. 4th Intl Conf. Disability, Virtual Reality & Assoc. Tech.,* Veszprém, Hungary.

Huang, H., S. L. Wolf and J. He (2006), Recent developments in biofeedback for neuromotor rehabilitation, *J Neuroengineering Rehabi,l* **3**: *11*.

D Jack, R Boian, A S Merians, M Tremaine, G C Burdea, S V Adamovich, M Recce and H Poizner (2001), Virtual reality-enhanced stroke rehabilitation, *IEEE Trans Neural Syst Rehabil Eng,* **9**, *3*, pp. 308-318.

G Kielhofner, L Borell, J Burke, C Helfrich and L Nygaardt (1995), *A Model of Human Occupation: Theory and Application,* Williams & Wilkins, Baltimore.

G Kielhofner and K Forsyth (1997), The Model of Human Occupation: an overview of current concepts, *British Journal of Occupational Therapy,* **60**, *3*, pp. 103-110.

J Kim, K Kim, D Y Kim, W H Chang, C I Park, S H Ohn, K Han, J Ku, S W Nam, I Y Kim and S I Kim (2007), Virtual environment training system for rehabilitation of stroke patients with unilateral neglect: crossing the virtual street, *Cyberpsychol Behav,* **10**, *1*, pp. 7-15.

K Kim, J Kim, J Ku, D Y Kim, W H Chang, D I Shin, J H Lee, I Y Kim and S I Kim (2004), A virtual reality assessment and training system for unilateral neglect, *Cyberpsychol Behav*, **7**, *6,* 742-749.

R Kizony, L Raz, N Katz, H Weingarden and P L Weiss (2005), Video-capture virtual reality system for patients with paraplegic spinal cord injury, *J Rehabil Res Dev,* **42**, *5*, pp. 595-608.

D Pierce (2001), Occupation by design: dimensions, therapeutic power, and creative process, *Am J Occup Ther,* **55**, *3*, pp. 249-259.

A A Rizzo and G J Kim (2005), A SWOT Analysis of the Field of Virtual Rehabilitation and Therapy, *In Presence: Teleoperators and Virtual Environments,* **14**, *2*, pp. 119-146.

O Spreen and E Strauss (1998), *A Compendium of Neuropsychological Tests,* Oxford University Press, New York.

T N Tombaugh (2004), Trail Making Test A and B: normative data stratified by age and education, Arch Clin Neuropsychol, **19**, *2*, pp.203-214.

C A Trombly and M Radomski (2002), *Occupational therapy for physical dysfunction*, Williams & Wilkins, Philadelphia.