Bilateral movement training with computer games for stroke rehabilitation

Marcus King and Juha Hijmans
Industrial Research Ltd.
P O Box 20028
Christchurch, New Zealand
+64 3 3586810
m.king@irl.cri.nz

Michael Sampson
Burwood Academy of Independent Living
Private Bag 4708
Christchurch, New Zealand

Jessica Satherley, Nicole McMillan and Leigh Hale
University of Otago
P O Box 56
Dunedin, New Zealand
+64 3 479 1100
leigh.hale@otago.ac.nz

ABSTRACT
Stroke is the most common cause of complex disability and many patients do not achieve adequate motor recovery of the upper limb with current rehabilitation procedures. Evidence supporting the use of bilateral arm training and virtual reality during stroke rehabilitation has been published. This paper describes two devices developed to use computer games during bilateral arm training. A pilot study of one of the devices showed a mean improvement in the upper limb section of the Fugl Meyer assessment of 4.2 (range 0-10), following a 10 session intervention. Clinician and end-user focus groups determined that the systems were acceptable forms of arm rehabilitation therapies.

Categories and Subject Descriptors
J.3 [**Computer Applications**]: Health

General Terms
Measurement, Performance, Design, Experimentation.

Keywords
Bilateral movement training, Stroke rehabilitation, Computer games.

1. INTRODUCTION
Stroke is the most common cause of complex disability [1], resulting in motor impairments such as muscle weakness, loss of range of motion, and reduced force generation [2] which can significantly limit daily activities and participation in family and social environments [2, 3]. The level of functional movement regained through therapy may be less than optimal due to rehabilitation being limited by resource allocation and patient access [4]. An estimated 30-60% of patients do not achieve adequate motor recovery of the upper limb with current rehabilitation procedures [5, 6]. In comparison, 82% of stroke survivors will learn to walk again [5]. This imbalance is largely due to the location of the stroke pathology but has also been attributed to early rehabilitation focusing on regaining lower limb and trunk control and movement to allow for the retraining of standing balance and walking [6].

It is suggested that the key features of upper limb rehabilitation should be task-oriented, focused on attention, repetition, intensity of practice, reward, progression of complexity, and skill acquisition, which are thought to help drive a change in neural structure and function [2]. Use of virtual reality (VR) during rehabilitation provides goal directed tasks with rewards and motivates the user to undertake extended rehabilitation [7]. Researchers have recommended further research into VR during rehabilitation [8].

A review of virtual reality-based interventions found advantages during stroke rehabilitation of the upper limb [9]. The interaction between the user and the virtual environment can be achieved through a variety of interface devices such as a computer mouse, a keyboard or a webcam [4, 10].

A meta-analysis found strong evidence supporting bilateral arm training during stroke rehabilitation [11] especially bilateral arm training with rhythmic auditory cueing (BATRAC) [12] and coupled bilateral and EMG-triggered neuromuscular stimulation [13]. However, these interventions alone do not provide the advantages of computer gaming as described above.

Recent interest has been shown for the use of the Nintendo Wii during stroke rehabilitation [14]. A similar commercially available device for motion gaming is the Cywee [15], but to date there appears to be no published research for the use of the Cywee as a rehabilitative tool. Use of such devices however requires the ability to lift the affected limb against gravity.

This paper describes two devices for combining bilateral exercises with computer gaming for survivors of stroke and reports a pilot study using one of the devices.

2. METHOD
2.1 Bilateral gaming device
2.1.1 Movement assisted gaming system
A bilateral symmetrical movement apparatus was developed where the user sits with their arms strapped onto forearm supports

and their hands resting on either joystick or palmar supports. Users are positioned for central alignment and table height is adjustable for ideal shoulder abduction. Reaching exercises train elbow flexion / extension, shoulder abduction / adduction and internal / external rotation via a coupled (passive) axial rotation with movement freedom below the forearm rest (Figure 1). A webcam allows movement of the affected hand to be displayed on the screen moving in a normal manner (analogues to mirror therapy), while interacting with a computer game.

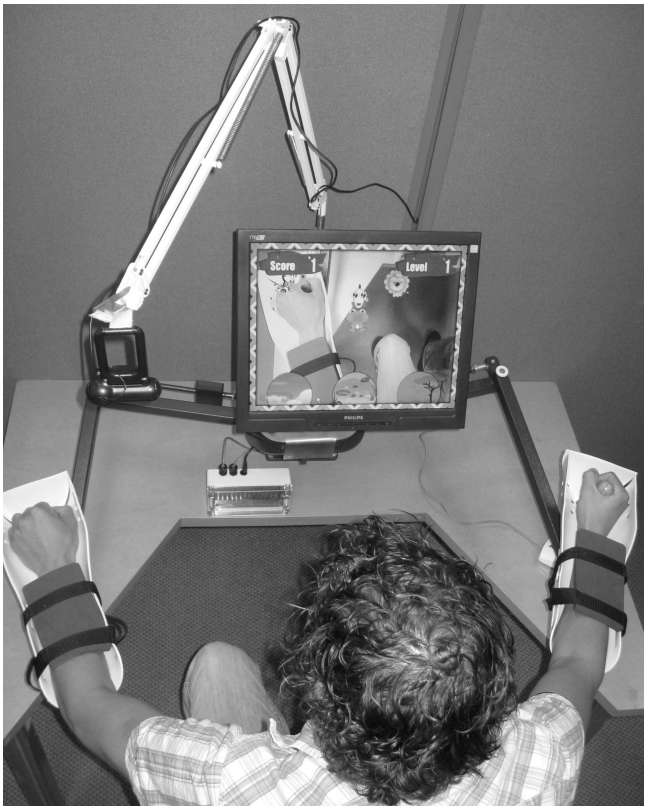

Figure 1 bilateral exerciser with webcamera game.

2.1.2 Movement-against-gravity gaming system

A three dimension movement game controller (Cywee Z controller, Taiwan) was used as the primary interface between the user and the computer. A handlebar (600g weight and 51cm long) was developed to encourage bilateral movement during use and allow people with stroke induced hemiparesis to gain support of their affected limb from their unaffected one (Figure 2).

As the Cywee requires rotation in both the sagittal and transverse planes to generate movement of the computer cursor, the handlebar forces the user to perform large shoulder and elbow movements for horizontal cursor movement and elbow flexion / extension and ulnar / radial deviation for vertical cursor movement during gameplay.

2.2 Computer game suite

Traditional computer games are designed for able-bodied gameplay and not suitable for rehabilitation, generally being too fast and providing negative feedback when loosing [16]. We created a suite of computer games that allowed a graduated series of physical challenges to be supplied from user-paced target hitting game similar to a slow paced "whack-a-mole", to faster sports games such as "airhockey". In addition, some casual games were supplied such as "mahjong" and "paint-by-numbers".

2.3 Study design

A mixed methods design was utilized.

2.3.1 Movement assisted gaming system

Two separate focus groups were held to explore the value of the movement assisted gaming systems. A physiotherapist skilled in the bilateral device application moderated the group using 6 prepared questions. The voice recording was transcribed word for word and thematically analysed.

For the clinician focus group included seven physiotherapists from five services organizations who work with survivors of stroke. The user focus group included five people with chronic stroke resulting in upper limb impairment, two field officers from the NZ Stroke Foundation and two partners of stroke survivors.

Figure 2: Cywee game controller fitted to bilateral handlebar.

2.3.2 Movement-against-gravity gaming system

This study used an AB design, starting with a control intervention followed by a wash out period and the actual intervention. Twenty-two participants were recruited from the local Stroke Club and via public media advertisements. Inclusion criteria were: aged 18 years or over, a diagnosis of stroke that occurred more than 6 months prior; presence of some voluntary movement in their arm affected by stroke; presently of good health; no self reported orthopaedic, medical or painful conditions that would prevent them from using the Cywee comfortably; and be able to provide written informed consent. Volunteers were excluded if they had fixed contractures in the affected upper limb preventing use of the Cywee; and / or an inability to understand the project and its requirements. Sixteen participants were eligible to participate. One participant dropped out prior to the study commencement and another prior to the intervention stage due to family commitments. Information regarding the participant's stroke and condition was obtained directly from the participant.

The hand holding the Cywee was determined by the participant's ability to successfully use the Cywee trigger switch with their affected hand and was positioned in the affected hand of 11

participants and in the non-affected hand of three participants. Soft bandaging was required to hold two participants affected hands onto the device as they lacked strength to grip the device independently.

Participants were tested before and after the control stage (T0 and T1), and before and after the intervention stage (T2 and T3) using the upper limb section of the Fugl-Meyer Assessment [17], the Wolf Motor Function Test [18] and the Disabilities of the Arm, Shoulder and Hand questionnaire (the DASH) [19, 20].

In the control stage participants played conventional computer games using a mouse with their non-affected upper limbs. The control stage consisted of 8-10 sessions, no longer than 1 hour each, over two and a half weeks. The participants then had a break of two to three weeks.

The intervention stage followed comprising 8-10 sessions, no longer than 1 hour each, over two and a half weeks. During each session participants played for as long as they could without becoming overly fatigued and took rest breaks as required. During the first intervention session participants learnt how to use the Cywee by playing simple target hitting games. In the second intervention session a more complex target hitting game was introduced. For the remaining 6-8 sessions participants were free to try the other games and play their preferred game/s. Therapist interaction time was similar during the control and the actual intervention.

For all three outcomes, an analysis of variance for repeated measures was used to test the effects of the three intervals over time using MedCalc V11 (2009). Ethical approval for the study was obtained from the University of Otago Human Ethics Committee (09/193).

3. RESULTS

3.1 Movement assisted gaming system

All therapists thought that they would use the device with their patients as a useful adjunct to physiotherapy; it would allow upper limb rehabilitation without impacting on therapist time and would assist rehabilitation of the primary functional upper limb task of reaching.

The user focus group participants indicated that the majority of their rehabilitation was focused on mobility rather than on retraining upper limb function. They were excited about the exercise device being targeted to the upper limb, but wanted the device to focus more on lifting the hand towards face and on retraining hand grasp functions.

3.2 Movement against gravity gaming system

There were 5 female and 9 male participants with an average age of 71 years (SD 12 years, range 47–85 years). The stroke affected 8 participants on their right side and 6 on their left side and time since stroke ranged from 1 year to 6 years. Only one participant was left side dominant, and that person's left side was affected by the stroke. Fugl Meyer scores at the start of the study varied from 14 to 64 (maximum score possible 66).

An average session was 50 minutes long with an average cumulative rest break within a session of 2 minutes. The rest breaks decreased as the sessions progressed and the active session length increased.

All participants reported that they enjoyed using the Cywee and felt they had derived tangible benefits from their involvement in the study. Two participants clearly described how their functional activity had improved, although four participants stated that they had experienced some shoulder pain while using the Cywee.

The Wolf Motor Function and DASH questionnaire showed no significant effect over time ($p=0.09$ and $p=0.21$, respectively).

A significant effect over time was found on the Fugl-Meyer Assessment ($p<0.001$). The mean improvement (Bonferroni corrected) of T3 compared to T0, T1, and T2 was 5.0 ($p=0.005$; 95% CI: 1.45 - 8.55), 5.2 ($p=0.002$; 95% CI: 1.80 - 8.66) and 4.2 ($p<0.001$; 95% CI: 1.81 - 6.66) respectively. The range of improvement of Fugl Meyer score was 0 to 10 (out of 66), so no participants deteriorated as a result of the intervention.

4. DISCUSSION

The movement assisted gaming device was considered useful by both therapists and users, although different needs were described by each group. The stroke survivor group was excited about an intervention focused on upper limb function while the therapist group considered the device to be a useful means of achieving upper limb rehabilitation without impacting too much on their limited time with the patient. This system is worthy of further development to allow survivors of stroke, with insufficient strength to move their affected limb independently, to use computer games for rehabilitation motivation. Additionally it may allow the user to observe their affected limb moving in a more normal manner similar to that seen with mirror therapy, which as currently used in upper limb stroke rehabilitation has shown positive effects on motor functioning, attributed to positive effects on brain plasticity [21].

This is the first study conducted using the Cywee as an upper limb rehabilitative tool. Participants enjoyed using the Cywee and felt they had benefited from it and although the Wolf and DASH showed little change, the Fugl Meyer results show a significant benefit for some.

Participants completing this pilot study had a wide range of impairment levels. The higher functioning participants felt that residual muscle weakness, rather than a problem with available range of motion of their upper limb joints, limited their initial ability to play the games and that their muscle strength appeared to improve over the course of the study. In a previous upper limb virtual reality study [10], strength showed the greatest improvements in comparison with changes in range of motion, suggesting there may have been improvements that were not picked up by the outcome measures used in this study and future studies should incorporate measures of upper limb muscle strength.

The first sessions with the Cywee were very fatiguing for most participants, reflected by the shorter session lengths and longer break times in session three compared with session seven. Additionally, some participants developed pain in their affected shoulder, possibly as a result of the rapid increase in arm use compared to pre-trial levels. While quantity, duration and intensity are important variables in relearning motor skills and changing neural structure [2], these results suggest that suitable protocols and assessment need to guide rehabilitation progression with this system to ensure sessions are pain free.

5. CONCLUSION

Participants in this pilot study reported physical and mental improvements and showed improvements in outcome measures following bilateral exercise while playing computer games. Furthermore focus group study confirmed acceptability of this form of intervention.

6. ACKNOWLEDGMENTS

We thank the Foundation for Research Science and Technology, NZ for funding this project, contract number C08X0404, the participants who willingly gave their time during the intervention and focus groups and Cerebralfix (NZ) and Im-Able (NZ) for developing the computer games.

7. REFERENCES

[1] Adamson J., Beswick A. and Ebrahim S., Is stroke the most common cause of disability? *J Stroke Cerebrovasc Dis.*, 13, 4 (2004), 171-177.

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

[3] Werner R. A. and Kessler S. Effectiveness of an intensive outpatient rehabilitation program for postacute stroke patients. *Am J Phys Med Rehabil*., 75, 2 (1996), 114-120.

[4] Sveistrup H. Motor rehabilitation using virtual rehabilitation. *J NeuroEngineering Rehabil.,* 1:10, (2004), 1-8.

[5] Umphred D. A. *Neurological Rehabilitation* 4th Ed. St Louis, USA: Mosby Incorporated, 2001.

[6] Lucca L. F. Virtual reality and motor rehabilitation of the upper limb after stroke: a generation of progress? *J Rehabil Med.*, 41, (2009), 1003-1006.

[7] King M., Hale L., Peffari A., Persson M., Gregorsson M. and Nilsson M. 2010 An affordable computerized, table-based exercise system for stroke survivors. *Dis Rehabil., (accepted for publication February 2010).*

[8] Henderson A., Korner-Bitensky N. and Levin M. Virtual reality in stroke rehabilitation: A systematic review of its effectiveness for upper limb motor recovery. *Top Stroke Rehabil.*; 14, (2007), 52-61.

[9] Cameirão M., Badia S. and Verschure P. Virtual reality based upper extremity rehabilitation following stroke: A review. *J CyberTherapy & Rehab*.; 1, (2008) 63-74.

[10] Holden M. K. and Dyar T. Virtual environment training: a new tool for neurorehabilitation. *Neurol Rep.,* 26, 2 (2002), 62-71.

[11] Cauraugh J. H., Lodha N., Naik S. K. and Summers J. J. Bilateral movement training and stroke motor recovery progress: A structured review and meta-analysis. *Hum Mov Sci.*, (2009), Retrieved 17 March, 2010 from: http://www.ncbi.nlm.nih.gov/pubmed/19926154

[12] Luft A R, McCombe-Waller S., Whitall J., Forrester L. W., Macko R., Sorkin J. D., Schulz J. B., Goldberg A. P. and Hanley D. F. Repetitive Bilateral Arm Training and Motor Cortex Activation in Chronic Stroke. *JAMA*., 292, 15 (2004), 1853-1861.

[13] Cauraugh J. H. and Kim S. Two coupled motor recovery protocols are better than one: electromyogram-triggered neuromuscular stimulation and bilateral movements. *Stroke.*, 33, 6 (2002), 1589-1594.

[14] Saposnik G., Mamdani M., Bayley M., Thorpe K. E., Hall J., Cohen L. G. and Teasell R. Effectiveness of Virtual Reality Exercises in STroke Rehabilitation (EVREST): rationale, design, and protocol of a pilot randomized clinical trial assessing the Wii gaming system. *Int J Stroke.,* 5, 1 (2010), 47-51.

[15] Anon. Cywee. Products introduction. (2010). Retrieved 27 January, 2010, from: http://www.cywee.com/en/product/product.jsp.

[16] IJsselsteijn W. A., Nap H., de Kort Y. A. W. and Poels K. Digital Game Design for Elderly Users. In *Proceedings of Futureplay 2007*. (Toronto, Canada, 14-18 November 2007), pp. 17-22.

[17] Platz T. (2005). ARM: arm rehabilitation measurement: manual for performance and scoring of the Fugl-Meyer test (arm section), Action Research Arm test, and the Box-and-Block test. Baden-Baden: Deutscher Wissenschafts-Verlag.

[18] Wolf S. L., Catlin P. A. Assessing Wolf Motor function Test as outcome measure for research in patients after stroke. *Stroke.,* 32, (2001), 1635-1639.

[19] Beaton D. E., Davis A. M., Hudak P. and McConnell S. The DASH (Disabilities of the Arm, Shoulder and Hand) outcome measure: what do we know about it now? *Br J Hand Ther*., 6, 4 (2001), 109-118

[20] McConnell S., Beaton D. E. and Bombardier C. The DASH outcome measure user's manual. Toronto: Institute for Work and Health 1999.

[21] Ramachandran V. S. and Altschuler E. L. The use of visual feedback, in particular mirror visual feedback, in restoring brain function. *Brain.,* 132, 7 (2009), 1693-1710.