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ORIGINAL REPORT

A FEASIBILITY STUDY USING INTERACTIVE COMMERCIAL OFF-THE-SHELF COMPUTER GAMING IN UPPER LIMB REHABILITATION IN PATIENTS AFTER STROKE

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Background: **Commercial off-the-shelf computer gaming devices have been making inroads into the rehabilitation arena, with the objective of making therapeutic exercise fun and contextual. One such device is the Nintendo Wii. Published clinical studies evaluating its acceptance, potential benefits and side-effects in the rehabilitation of patients with post-stroke weakness are few in number.**
Objective: **The aim of this study is to assess the feasibility of using the Nintendo Wii as an adjunct to conventional rehabilitation of patients with post-stroke upper limb weakness.**
Methods: **Twenty rehabilitation inpatients within 3 months after a stroke with upper limb weakness received 6 sessions of upper limb exercises via a Nintendo Wii over 2 weeks in addition to conventional rehabilitation. Outcome measures include a questionnaire, Fugl-Meyer Assessment of Upper Limb Motor Function and visual analogue scale of upper limb pain.**
Results: **A total of 16 subjects completed the study. All 16 found Nintendo Wii gaming enjoyable and comparable to, if not better than, conventional therapy. There were small but statistically significant improvements in the Fugl-Meyer Assessment and Motricity Index scores.**
Conclusion: **Nintendo Wii appears to be a feasible adjunctive device to augment conventional therapy in a cohort of subacute stroke patients with moderate impairments of upper limb strength and function.**

Key words: rehabilitation; Nintendo Wii; commercial off-the-shelf; upper limb weakness; computer gaming; stroke.

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INTRODUCTION

Interactive computer gaming has been making inroads into the rehabilitation arena, with the objective of making therapeutic exercise fun and contextual (1–5). One such device is the Nintendo Wii™ (NW) gaming system, which was released commercially at the end of 2006. NW detects the user's movement and acceleration in 3 dimensions using a wireless handheld pointing device (Wiimote) housing a gyroscope and an accelerometer. Using various commercially available games (including sports themed games), the player uses part or whole of the upper limb to perform tasks (e.g. swinging a virtual tennis racket or throwing a virtual bowling ball). The games are designed to be fun and interactive, with scores and various motivational features (e.g. in-game medals, encouraging commentaries, video playbacks, bonuses, music, etc.) to encourage the user repetitively to improve his or her performance.

An important key to rehabilitation is repetitive and task-specific exercises (6); over time patients may find such exercises monotonous and boring and may lose motivation. The need to stay motivated in therapy programmes has prompted the additional use of gaming to the well-researched constraint-induced movement therapy methodology (7). NW's fun and interactive approach may motivate patients to increase participation and, ultimately, may lead to better therapy results.

Apart from a case report on the use of NW in a child with cerebral palsy (8) and another on the use of Sony EyeToy™ (9), there are few published clinical studies evaluating the acceptance, potential benefits and side-effects of using a commercial off-the-shelf (COTS) interactive computer gaming device in the rehabilitation of patients with post-stroke weakness. In this context various questions arise, as follows. Can patients with weakness use the device, which was built mainly for able-bodied users? Will patients find NW fun and acceptable in a therapeutic environment? Are there side-effects when NW is used for rehabilitation of stroke? How does its use as an add-on to conventional upper limb therapy affect patients' motor outcome?

This study aims to assess the feasibility of using such a COTS device as an adjunct to conventional rehabilitation of patients with post-stroke upper limb weakness.

METHODS

Subject and design

This is a pilot study of 20 consecutive patients after stroke with upper limb weakness. The patients were recruited from the inpatient rehabilitation unit of a Singapore Rehabilitation Centre at a mean of 26.3

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days after stroke onset. Patients were included if they were less than 3 months post-stroke, had Medical Research Council (MRC) motor power of at least grade 2 in the hemiplegic upper extremity, were able to understand simple instructions and learn. They were excluded if they had a history of epilepsy, arthritis or pain in the affected upper limb restricting repetitive exercises, severe aphasia or cognitive impairment, or other psychiatric illnesses that limited their ability to participate or give consent. The demographic and clinical characteristics of the subjects are shown in Table I. The cohort is relatively young, with a mean age of 64.5 years. The majority of patients had moderate upper limb impairment and weakness, as evidenced by a Fugl-Meyer Assessment (FMA) score of 41.1 and Motricity score of 9. A significant proportion of subjects (60%) had only primary education. Six subjects had poor distal power of their upper limbs and 2 subjects had hemi-sensory deficits, but none had neglect. Medical co-morbidities included hypertension (15 subjects), diabetes mellitus (7 subjects), hyperlipidaemia (7 subjects), ischaemic heart disease (1 subject) and previous stroke (4 subjects).

The study was approved by the ethics review board of the hospital.

Intervention

Set-up and calibration of NW. NW detects specific movements and acceleration in 3 dimensions, via a wireless handheld pointing device (Wiimote™), held by the user, and a sensor bar connected to the console. Different games are designed to test the skills of the user in executing different movements and acceleration of the upper limbs as specified by the games. Scores are given and users with better precision in executing each task attain higher scores.

The NW was set up and calibrated before each training session to ensure that the patient was able to point correctly at the sensor. The sensor was positioned either above the television (for subjects who could stand) or at the base of television (for subjects in a wheelchair). The subject was asked to hold the Wiimote. For subjects with weak or no grasp, the Wiimote was strapped to their hand by either a customized fabric grasp assist, or simply with crepe bandage. These adaptations were made after the therapist had assessed the subject's hand function at the beginning of the first session.

Selection of games. Games from the Wii Sports software were used. The games included boxing, bowling, tennis, golf and baseball. Each game or part of a game was pre-selected taking into consideration individual patient's preferences and residual upper limb functional capacity as determined by the occupational therapists. Hence different games or parts of the game were used for different subjects. All the games could be played in both sitting and standing positions, depending on the subject's balance capability.

Duration of intervention. The training comprised 6 sessions over 2 weeks, with each session lasting 30 min (excluding set-up time). In addition to NW gaming, all subjects also received at least 1 h of occupational therapy and 1 h of physical therapy daily, except for at weekends.

Computer gaming experience and pre-intervention patient feedback. An interviewer-administered questionnaire was designed to evaluate acceptance of use of NW. The questionnaire comprised 2 parts. The first part was applied prior to the intervention; subjects were asked about their previous experiences with computer gaming and use of NW and whether they would consider computer gaming as a pastime and as part of their treatment regime. The second part of the questionnaire was applied after completion of training; subjects were asked to comment on the use of NW and issues encountered. They were also asked whether it was enjoyable, should NW be recommended as part of the rehabilitation programme and whether it was superior to conventional rehabilitation. With regards to computer gaming experience, 16 (80%) subjects had never previously played computer games, 3 played occasionally and 1 sometimes. No subject had ever played a Wii game previously. Four (20%) subjects would consider computer gaming as a leisure pursuit, 9 (45%) would not, and 7 (35%) were unsure. When asked if computer gaming could be used to facilitate stroke rehabilitation, 6 (30%) subjects said yes, 1 (5%) said no and the remaining 13 (65%) were unsure.

The mean age of subjects who had no gaming experience was 66.6 (8.9) years compared with 56.3 (8.8) years for those who had. This difference was, however, statistically insignificant (Wilcoxon test, $p = 0.058$). The only significant correlate was the subject's educational status. Those who had primary education or lower were more likely to have no previous gaming experience (Fisher's exact test, $p = 0.014$).

Clinical evaluation

The following outcome measures were evaluated at baseline and on completion of the 6 sessions of training: the Fugl-Meyer Assessment of Upper Limb Motor Function (FMA) (10); Motricity Index, which is a summation of the best motor power of the shoulder, elbow and fingers. Thus the score ranged from 0 to 15; Modified Ashworth Scale (MAS) for assessment of muscle tone of the shoulder, elbow and wrist (11); and visual analogue scale (VAS) for upper limb pain (score of 0–10).

Statistical analysis

The results of continuous data were expressed as mean (standard deviation). For comparison of FMA, Motricity Index, MAS and VAS Pain scores before and after computer gaming, the non-parametric Wilcoxon test was used. For test of association between categorical variables, the χ^2 or Fisher's exact test, where appropriate, was used. The level of statistical significance was set at $p < 0.05$.

Table I. *Characteristics of the subjects participating in the study (n = 20)*

Characteristics	
Age, years, mean (SD)	64.5 (9.6)
Sex, *n* (%)	
Male	13 (65)
Female	7 (35)
Educational status, *n* (%)	
Primary	12 (60)
Secondary	3 (15)
Tertiary	5 (25)
Time from stroke onset to enrolment, days, mean (SD)	26.3 (13.2)
Nature of stroke, *n* (%)	
Infarct	19 (95)
Haemorrhage	1 (5)
Site of stroke, *n* (%)	
Cortical	10 (50)
Subcortical	8 (40)
Brainstem	2 (10)
Side of hemiplegia, *n* (%)	
Left	10 (50)
Right	10 (50)
Sensory impairment, *n*	
Yes	2
No	18
FMA, baseline, mean (SD)	41.1 (17.9)
Motricity score, baseline, mean (SD)	9.1 (2.5)
Total MAS score, baseline, mean (SD)	0.63 (0.96)

FMA: Fugl-Meyer Assessment; MAS: Modified Ashworth Scale; SD: standard deviation.

RESULTS

Outcome measures

Sixteen subjects completed the study. Of the 4 who did not, 1 required management of other medical problems and was transferred out of the centre, 2 felt lethargic when combining conventional therapy with gaming sessions and decided to discontinue after the first gaming session, and 1 was discharged earlier than expected and could only complete 5 of the 6 scheduled sessions.

For analysis of data before and after intervention, only the data of the 16 subjects who completed the study were analysed. Changes in the FMA, Motricity Index, MAS and VAS Pain scores before and after intervention are shown in Table II. This revealed statistically significant improvements in the FMA and Motricity Index scores, indicating that subjects had better upper limb motor power and function than before the study.

Adverse events

In addition, all side-effects and adverse events during intervention were documented after each session. A total of 5 adverse events was reported. Two subjects complained of lethargy and fatigue after the first session and withdrew. Of the others who completed a total of 96 sessions (16 × 6 sessions), there were 3 cases of mild pain and soreness of the upper limb, which lasted less than one day and did not affect their participation in therapy.

Feedback on computer gaming from subjects who completed the study

Six subjects found use of the NW very enjoyable, 7 quite enjoyable and 3 found it slightly enjoyable. Problems encountered during the intervention included difficulty holding the Wiimote due to poor distal limb function (6 patients) and inability to understand the games due to unfamiliar language as the games and gaming instructions were in English (12 subjects had primary education or less and all of them were English illiterate). These problems were overcome by strapping, as described in the methodology section, and translation by the occupational therapists. When asked how the intervention was compared with conventional therapy as provided by the occupational therapist, 11 subjects reported that the intervention was as useful as conventional therapy, 4 reported that it was complementary to conventional therapy, and 1 reported that NW gaming was better than conventional therapy. Fourteen subjects would have liked NW gaming to continue as part of their rehabilitation programme, while 2 were uncertain. Finally, when asked if they would recommend NW gaming to other patients, 8 answered “definitely yes”, 7 “yes” and 1 “maybe”.

DISCUSSION

This study was limited by the small sample size and non-controlled design, but the results showed that the use of NW gaming seemed to be acceptable from the perspective of subacute stroke patients with upper limb weakness. Eighty percent (16 of 20 subjects) completed the study; the 2 who chose to drop out voluntarily did so after the very first session citing lethargy and lack of interest as the reason. Feedback on patients’ experience of the use of NW gaming was overwhelmingly positive in those who completed the study, with 75% (12 of 16 subjects) indicating that it felt subjectively as useful as, if not better, than conventional rehabilitation; 81.3% (13 of 16 subjects) finding it fairly to highly enjoyable, 87.5% (14 of 16 subjects) wanting this to be continued as part of their rehabilitation programme and 93.8% (15 of 16 subjects) willing to recommend it to other patients. These results were all the more impressive as most subjects had no or little prior computer gaming experience and 65% were not sure at baseline about the role of NW gaming in stroke rehabilitation. One word of caution however; although these results may mean that NW gaming is fun and thus acceptable to patients, they cannot be interpreted to mean it is clinically useful.

However, this study did show that, even in stroke patients with moderately severe upper limb impairments, NW gaming, which requires the patient to move a pointing device strapped to their upper limb, can be achieved and accepted; provided proper calibration, strapping and choice of games are carried out by the occupational therapists in consultation with the patients. Most of the study subjects wanted to continue using NW as part of their rehabilitation programme; thus the fun and appeal of NW and perhaps interactive computer gaming in general in rehabilitation cannot be ignored. Use of NW gaming may engage patients who otherwise lack interest or motivation to complete normal exercise regimens. At present NW gaming cannot replace conventional rehabilitation, but it does add a dimension of entertainment. It may offer an opportunity for socialization and leisure, for example if patients use it in pairs or in groups supervised by the therapists. Utilizing patient leisure skills during computer gaming can be effective in the inpatient rehabilitation setting to provide skills exploration and to increase motivation.

This study was conducted as an extension of occupational therapy for the subjects. Well established in the practice philosophy of occupational therapy is the therapeutic use of purposeful activities, which are a subset of occupations (i.e. activities pertaining to daily living, productivity, leisure and personal meaning), to enhance human function (12). In a review of occupational therapy studies, it has also been recommended that games and meaningful activities be used to increase participation and therapeutic effect (13).

Playing an interactive game, such as with the NW, requires not only sensory-motor function inputs but cognitive inputs as well, as the player is required to attend, comprehend, recall, and plan and execute appropriate responses to the visual cues provided on the screen. Thus, despite awareness of arm movements being at a subconscious level while concentrating on the game, patient-players have shown to be highly engaged with the activity (14). In addition, the goal-directed responses elicited in gaming can foster sustained participation and, ultimately, motivation (15).

Table II. *Fugl-Meyer Assessment (FMA), Motricity Index, Modified Ashworth Scale (MAS) and pain scores*

	Pre-gaming	Post-gaming	*p*-value
FMA, mean (SD)	41.1 (17.9)	46.1 (18.6)	0.007
Motricity index, mean (SD)	9.1 (2.5)	9.7 (3.0)	0.031
MAS, mean (SD)	0.63 (0.96)	0.50 (0.89)	0.32
Pain, mean (SD)	0.44 (1.75)	0.31 (1.25)	0.33

SD: standard deviation.

Life satisfaction and quality of life following stroke is related to leisure activity, hence it is important to address the patient's social and leisure needs when developing long-term rehabilitation goals (16). NW, being COTS and relatively cheap, has the potential to be used on a longer term basis, as an adjunctive outpatient rehabilitation tool and perhaps even in community or home rehabilitation, to address the leisure needs of patients.

The intervention was well tolerated generally. With the exception of 2 subjects who dropped out because of fatigue, there were few adverse events. All were related to mild pain and soreness of the upper limb that lasted less than a day and did not affect the subjects' participation in rehabilitation. This is similar to "Wii shoulder", "Wii elbow" and "Wiinitis" as described in the literature (17–19). Pain was not a major problem in this short study, as evidenced by the low VAS pain scores before and after intervention. Of concern, however, is the question of whether more repeated and intensive NW gaming sessions would increase the risk of musculoskeletal-related pain and problems such as repetitive strain injury. Frequent computer-related activities may increase the risk of neck-shoulder and low back pain in adolescents (20) and the repetitive strain induced "Wii shoulder", Wii elbow" and "Wiiinitis" (17–19). Care must be exercised, as the presence of muscle weakness, flaccidity, impaired joint stability and support, e.g. shoulder subluxation, abnormal joint biomechanics and sensory impairment, make the hemiplegic upper limb susceptible to trauma, even if this is mild. The duration of intervention needs to be short, and supervision is important.

Another concern is that of epileptic seizure, which is a possible adverse effect of participation in computer gaming, and is quoted by Nintendo Wii as 1 in 4000. This figure is similar to that reported in the literature (21–24). Stroke patients have a mean 11.5% risk of single or recurrent seizures in the first 5 years after a stroke, and those with more severe strokes or haemorrhagic strokes are at higher risk (25). There is currently no data on whether repeated video/computer-gaming increases the risk of seizures in stroke patients without history of seizures.

NW is relatively cheap and commercially available for study. Previous studies using computer gaming in rehabilitation mainly involved custom-made devices that were not commercially available and were restricted to selected institutions. The only controlled study using a commercially available computer game is that by Yavuzer et al. (9), involving the Playstation EyeTo™ games. Twenty patients with subacute to chronic stroke undergoing inpatient rehabilitation were randomized to either playing "Playstation Eye Toys" or just watching the games (without physical involvement) daily for 4 weeks, with each gaming session lasting approximately 30 min. The authors reported significantly higher self-care FIM scores in the treatment group. Whether FIM score is the most appropriate functional indicator in this type of setting is perhaps debatable.

Although statistically significant improvements in the FMA and Motricity Index scores post-intervention were noted in our study, the efficacy of NW gaming in augmenting functional outcome is uncertain as there was no control group and subjects were receiving conventional rehabilitation at the same time. Furthermore, as patients were evaluated at 26.3 days post-stroke, the contribution of spontaneous recovery cannot be ruled out. Significant upper limb recovery usually occurs within the first 6 months after stroke (26–27).

In conclusion, the use of COTS computer gaming, such as NW, appears to be a feasible adjunctive device to augment conventional therapy in a cohort of subacute stroke patients with moderate impairments of upper limb strength and function. Further controlled studies are needed to evaluate whether it is independently effective compared with conventional rehabilitation in improving upper limb function and, if so, whether these improvements are translated to improved use of the affected extremity as well as performance in activities of daily living. Many questions about the role of computer gaming in rehabilitation remain; for example, how to quantify motivation and participation, how to individualize gaming protocol for different types of patients, safety and usability issues during longer term or home use, etc. Further research is needed to answer these and other practical questions as more and more centres adopt computer gaming in their rehabilitation programmes.

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