Home-based stroke rehabilitation using computer gaming

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ABSTRACT

This paper reports the findings of a case series of home-based bilateral upper limb rehabilitation using a motion-based computer game controller. Three individuals with chronic stroke and upper limb hemiparesis, who had previously participated in the initial trial of the system, continued rehabilitation for between 55 and 61 days at home, as recorded by diaries of use. Each participant was tested pre- and post-intervention using the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire, and post-intervention, by the Intrinsic Motivation Inventory (IMI). Body function outcome measures were the Fugl Meyer Upper Extremity Assessment (FMA) and the Motor Assessment Scale (MAS). Although motor performance change was inconclusive, motivation assessment showed a trend of positive engagement, and the participants practiced unsupervised for 4.5 to 5.5 sessions per week over the duration of the trial, each achieving at least 33.5 hours of exercise.

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INTRODUCTION

Worldwide, about 15 million people per year suffer from a stroke (Mackay and Mensah 2004). Of the two thirds who survive, effects on body function (motor) commonly include muscle weakness, loss of range of motion, dyscoordination and spasticity, which often significantly limit activities of daily living and participation (Nakayama et al 1994, Werner and Kessler 1996). Following stroke, up to 85% of survivors initially show a motor deficit of the arm contralateral to the lesion. By six months, 30 to 66% of individuals still do not have functional upper limb activity (Richards et al 2008) and it is estimated that only 5 to 20% of people with stroke attain complete functional recovery of their affected upper limb (Kwakkel et al 2003).

Although most recovery of upper limb function occurs in the first three months after a stroke, significant gains in dexterity, strength and function with rehabilitation six months or more post-stroke, have been reported (Merians et al 2002, Werner and Kessler 1996). It is suggested that the application of rehabilitation techniques that enhance the brain's capability for neural plasticity and recovery after stroke, offer the best chance for upper limb functional recovery and motor relearning (Duncan et al 2005, Kleim and Jones 2008). Requirements for facilitating such neural plasticity are therapies that gain the attention of patients, and provide sufficient repetition and intensity of practice, i.e. duration and frequency of exercise (Henderson et al 2007, Kleim and Jones 2008, Krebs et al 2009, Kwakkel et al 2008, Sveistrup 2004).To gain or maintain attention, in a repetitive and functional/task-based way, requires exercises that are motivating and engaging (Merians et al 2002). Safely facilitating patients with stroke to complete a sufficient quantity of therapy that realises their true motor recovery potential can be achieved in a variety of ways. There appears to be little difference in the functional outcomes of a number of conventional stroke rehabilitation techniques, such as neurodevelopmental techniques and motor relearning (Saposnik et al 2011). Investigations into the contribution of newer technologies or approaches to stroke rehabilitation is warranted.

Computer-assisted virtual reality (VR) technology, although a relative newcomer to the stroke upper limb therapy tool box, shows promise. In a review of the effect of seven trials of VR on upper limb function, Laver et al (2011) found that VR was moderately more effective than conventional interventions, although small sample sizes and heterogeneity of interventions limited this interpretation. Although VR requires further investigation, it could potentially be integrated into conventional rehabilitation or be used alone when conventional rehabilitation is unavailable or restricted (Burdea and Coiffet 2003, Saposnik et al 2011). Low-cost, motivating and engaging VR rehabilitation systems with low therapist supervision requirements offer potential for use in community rehabilitation or outpatient facilities. This is particularly relevant given that hospital-based and home-based stroke rehabilitation are known to be similarly effective (Teasell et al 2008), and given the interest in home-based stroke rehabilitation (Forster and Young 1990, Young 1994).

The release of the New Zealand Health Strategy Discussion Document (2000) targeted community-based initiatives and supported community stroke rehabilitation. Currently, the New Zealand Clinical Guidelines for Stroke Management (Stroke Foundation of New Zealand and New Zealand Guidelines Group 2010) recommend *interdisciplinary community rehabilitation* and *early supported discharge … to all people with stroke …* (p95). Evidence suggests that approximately 65% of patients are likely to be generally non-adherent to some degree to physiotherapy rehabilitation programmes (Bassett 2003). However, there is evidence to support greater adherence to home-based rehabilitation in stroke compared to clinic-based rehabilitation and improved aptitude of patients to undertake personal activities of daily living with reduced risk of deterioration in ability (Legg et al 2004, Duncan et al 2011).

Evidence exists for the use of bilateral therapy for upper limb hemiplegia, whether synchronous or asynchronous, using assistive devices, or as a motor priming activity (Ausenda and Carnovali 2011; Cauraugh et al 2010; Sampson et al 2012; Stewart et al 2006). As unilateral and bilateral training are similarly effective (van Delden et al 2012) it is possible that future research into matching the best technique for any given stroke patient/pathology may also be important. In a pilot study of 14 participants with chronic-stroke and upper limb hemiplegia, Hijmans et al (2011) found that playing computer games with a bilateral motion-based controller led to a significant gain in Fugl-Meyer Assessment-Upper Extremity (FMA). That study provided bilateral therapy using a modified handlebar to link the arms so that the unaffected arm was able to (self) assist the affected arm. The resulting movement patterns generated were able to be synchronous/mirrored or asynchronous. As this therapy is low-cost with modest space requirements, and is able to be used with a personal computer, it could be used within home environments.

There remains a need to further test if VR systems engage and motivate users sufficiently to achieve an intensity of practice where functional and motor recovery is likely to be positively influenced. In a systematic review of upper limb therapies, Kwakkel et al (2004) concluded that a minimum of 16 hours of therapy in the first six months post-stroke improved activities of daily living outcomes and that engaging in more hours per week was a factor that likely enhanced rate of recovery. We have not found any evidence specifically quantifying engagement and motivation in post-stroke upper limb home therapy though, particularly within the context of computer game activity as therapy. There are limitations with unsupervised or minimally supervised computer facilitated rehabilitation, such as a lack of guidance of motor control facilitation, limited range of actual utilised movement, or lack of controls on compensatory action sequences and compounded movement errors. However, it is worthwhile to establish feasibility in the home environment and to test if users will practice sufficiently without the presence of therapists and their associated extrinsic motivation.

The aim of this study was to investigate the potential of bilateral therapy and computer games played via a motion-based controller as home therapy. We used a case series to assess user engagement in the home environment where there was minimal informal supervision and no therapist supervision for a time period at least longer than six weeks.

METHODS

Participants

Three volunteer participants with chronic, post-stroke upper limb hemiplegia, and who had previously participated in a trial of 10 sessions of bilateral therapy using VR (Hijmans et al 2011), were recruited to participate in home-based therapy for a period of 8 weeks. Screening by a registered physiotherapist was conducted using the following criteria: a) Inclusion: 18 years or over with a confirmed diagnosis of stroke that occurred more than six months prior; limited voluntary movement in their arm affected by stroke; no self-reported orthopaedic or medical conditions or pain preventing them from using the bilateral exercise device comfortably (practically checked); and the ability to provide written informed consent. Exclusion: fixed contractures in the affected upper limb preventing effective and/or safe use of the device; inability to understand the project and its requirements (e.g. due to confirmed diagnosis of dementia or receptive aphasia or per clinical judgement). Information regarding the participant's stroke was obtained directly from the participant.

All participants provided signed informed consent and the study was approved by the University of Otago Human Ethics Committee (09/193).

Study design

A pre-post intervention design was utilised. Participants were assessed (T1), home intervention was performed, and reassessment (T2) occurred in the week following the cessation of intervention.

Outcome measures

a) Primary outcome measures.

(i) Participant diaries of adherence to the intervention: Patient self-reports are suggested as an ideal method of evaluating adherence to home-based physiotherapy (Bassett 2003). To assess patient engagement quantitatively, we used participant diaries to record occurrence and duration of the intervention.

(ii) Intrinsic Motivation Inventory (IMI): A 32 question IMI was used to measure post-intervention motivation (Selfdeterminationtheory.org 2012, McAuley et al 1989). The IMI has validity as a post-intervention measure (McAuley et al 1989) and although it measures several domains, it is the interest/enjoyment domain that primarily assesses intrinsic motivation *per se*. The IMI's questions are face valid and straightforward, having been found to be stable and coherent across a wide range of tasks, conditions and settings (Selfdeterminationtheory.org 2012). The IMI uses a Likert scale that asks the user to rank the statements according to 'how true they are' for them, ranked from 1 (not at all true), 2, 3, 4 (somewhat true), 5, 6, to 7 (very true). An interest/enjoyment score indicating the answers were 4 or more on average would represent positive intrinsic motivation. To check for ego involvement or pressured performance, the perceived choice domain assesses free choice behaviour, allowing correlation with the interest/enjoyment domain. Appendix 1 contains sample questions from each IMI domain.

(iii) Disabilities of Arm, Shoulder and Hand (DASH) questionnaire: To assess participant perceived change in upper limb physical functioning through a range of activities we used the DASH pre- and post-intervention (Hudak et al 1996, Beaton et al 2001). Originally developed for use in musculoskeletal conditions, the DASH is an extensively used, reliable, valid and responsive measure of upper limb physical function (Bot et al 2004).

b) Secondary outcome measures (of body function).

(i) The Fugl-Meyer-Upper Extremity (FMA): The FMA scores motor function out of a total of 66, a higher score indicating better motor function (Fugl-Meyer et al 1975).

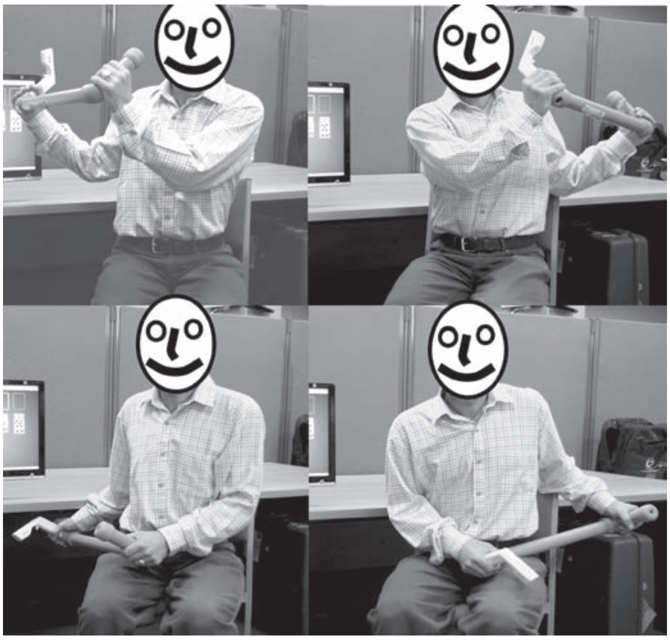
(ii) Motor Assessment Scale (MAS): The MAS (Carr et al 1985) is an eight section assessment of stroke motor function. Each section contains six motor tasks from easiest (score = 1) to most difficult (score = 6), where the best of three attempts is recorded. A zero is recorded if none of the tasks are able to be performed and a six indicates optimal performance in each section. We used the upper limb, hand and advanced hand tasks sections only.

Both the FMA and the MAS are extensively used, reliable and validated functional outcome measures in stroke rehabilitation research (Salter et al 2012).

Hardware

The CyWee Z controller (Cywee Inc., Taiwan), a motion-sensor based game controller similar to the Nintendo Wii remote, was used to control the on-screen cursor of the personal computer-based games. It was incorporated into a handlebar measuring 35-50 cm long (Figure 1). Rotations of the device in the transverse plane produce horizontal mouse cursor translations on the screen, and rotations in the sagittal plane produce vertical mouse cursor translations. A trigger on the Cywee Z acted as a left mouse button.

Figure 1: CyWee Z incorporated into a handlebar showing range of movements required to play the computer games



Software

A suite of computer games with a range of movement, reaction, speed and accuracy challenges were used to promote engaging bilateral movement exercises. The cognitive requirements to play the games were low. The games were either specifically developed, or adapted to provide clear graphics and achievable motor demands, thereby allowing participants to understand and use the games quickly. The following games were used: stationary target hitting games ("Whack a mole") and strategic target hitting games ("Bejewelled" and "Balloon Popping"), moving target hitting games ("Mosquito Swat", "Music Catch" and "ReBounce"), faster sports games ("Air Hockey"), and puzzle games ("Mah-Jong" and "Solitaire"). All games required large cursor movements in both horizontal and vertical directions. Knowledge of results was provided in all games via scores based on time taken, number of successful 'hits', reaction speed and accuracy.

Intervention

To ensure that the systems could be independently operated at home, the participants were orientated, taught and observed sufficiently in the hardware set up, software use and game practice, before the systems were left with them. They then played the games at home over a period of up to 61 days. If the participants were able to use the trigger button of the CyWee Z with their affected hand, the CyWee Z was used in that hand (n=1). If not, the CyWee Z was held in the unaffected hand. If grip strength in the affected hand was insufficient to hold the handlebar, a soft Velcro binder was used to hold the device in their affected hand (n=1). The binder was designed so that it could be independently self-applied. Participants chose when and for how long they played for in each session; however, they were instructed to play for no longer than 90 minutes on any given day. This was a guideline to safeguard against repetitive strain injury whilst still allowing reasonable flexibility with regard to the expression of individual engagement. Participants kept diaries of session duration and days played. Each individual game was played at least once, after which participants were free to choose the proportion of time they spent on any particular game or games. The rationale for allowing the participants to choose what games they played thereafter was to maximise engagement and allow free choice behaviour at least within the limits of the game suite provided. As all the games were designed to promote 'target-hitting', albeit with different visual and play 'themes,' they similarly required participants to exercise through a varied, yet achievable range of arm movements both in direction and reach.

RESULTS

There were no reports of adverse reactions, accidents/injury or prolonged soft tissue irritation from participant use of the intervention.

The participants, two males and one female aged 47 – 65 years, all were more than 18 months post stroke. The dominant side for Participant 3 (P3) was his affected side whereas Participant 1 (P1) and Participant 2 (P2) both were affected on their non-dominant side. Table 1 provides a summary of participant characteristics.

Table 1: Participant characteristics

Participant	P1	P2	P3
Age (years)	65	47	57
Sex	Male	Female	Male
Ethnicity	New Zealand European	New Zealand European	New Zealand European
Affected side	Left	Left	Right
Hand dominance	Right	Right	Right
Time post stroke	18 months	27 months	28 months

Table 2: Primary outcome measures

Participant		P1	P2	P3
Diary:	Number of days intervention used/Total intervention period	44 / 55 days	46 / 58 days	49 / 61 days
Diary:	Average session duration (minutes)	46 mins	35 mins	38 mins
Diary:	Average sessions per week	5.5	5.5	4.5
Diary:	Total hours of intervention	42.3 hrs	33.5 hrs	39.7 hrs
DASH:	Pre intervention : Post intervention (/100)*	23 : 23	50 : 39	40 : 46
IMI	Interest/Enjoyment (/49)	35 (71%)	37 (76%)	22 (45%)
IMI	Perceived Choice (/49)	18 (37%)	19 (39%)	18 (37%)
IMI	Perceived Competence (/42)	32 (76%)	30 (71%)	22 (52%)
IMI	Value/Usefulness (/49)	49 (100%)	49 (100%)	32 (65%)
IMI	Effort/Importance (/35)	23 (66%)	23 (66%)	16 (46%)

*Decrease indicates improvement

Tables 2 and 3 display the results of the primary and secondary outcome measures. These results show that the participants used the device regularly over the period of the home trial and that the intervention was motivating to them. Each participant used the device for 33.5 hours or more over the trial period. Body function change scores were inconclusive

Table 3: Secondary outcome measures

Participant	P1	P2	P3
FMA pre intervention (/66)	57	57	24
FMA post intervention (/66)	57	57	26
MAS pre intervention (/18)	12	10	NT
MAS post intervention (/18)	14	14	NT

NT: Not tested (participant unavailable)

DISCUSSION

All participants demonstrated engagement with the intervention by regularly exercising unsupervised for greater than or equal to 35 minutes per session and for greater than or equal to 4.5 times per week over the 6 week intervention period. This was a positive finding, as it was not clear whether the participants would regularly use the intervention over an extended time period without direct therapist input. A justification for using VR in stroke rehabilitation is the argument that people are motivated by it and thus the desired repetitive practice of upper limb movement to facilitate neuroplasticity is gained (Crosbie et al 2009, Merians et al 2002, Sveistrup 2004). No previous study appears to have investigated this premise in a home-based setting over an extended time. Given that all participants completed greater than 33.5 hours of intervention, they more than fulfilled the required minimum 16 hours of therapy likely to enhance recovery (Kwakkel et al 2004).

P1 and P2 had IMI interest/enjoyment scores of respectively, 71% and 76% and high ratings for value/usefulness. These contrasted with their 37% and 39% perceived choice scores and do temper the IMI's strength in assessing their intrinsic motivation. However, as interest/enjoyment is the key measure of intrinsic motivation, a motivating experience can reasonably be assumed from these scores.

In contrast, P3's interest/enjoyment and perceived choice scores were more correlated than those for P1 and P2, yet lower (45% and 37%). Possibly, P1 and P2 had greater "ego" involvement than P3 and this was reflected in their uncorrelated perceived choice scores (i.e. more self-expectation to perform at a perceived level). There could be many reasons for P3's lower IMI scores, although it is notable that he had been affected by stroke for the longest duration and had hemiplegia on his dominant side. A larger sample and perhaps the use of focussed interviews or other outcome measures is necessary to further explore the associations between various IMI scores and the intervention. Also, comparing outcomes from individual home use of the intervention with individual use within a group (social) setting may help to explore the effects of intrinsic versus extrinsic motivation in stroke upper limb therapy.

DASH scores demonstrated variable perceptions of change in physical symptoms and performance over the intervention period: P1 did not change, P2 improved and P3 declined. These self-reports do not appear to consistently correlate with the change in FMA or MAS scores. P2 gained four MAS points, mainly due to improved hand function, but did not change as measured by the FMA. This perceived hand improvement may have been revealed by the DASH score as a key factor for P2 with the FMA simply being a less sensitive measure of hand function. Interestingly, the overall physical design of the intervention was such that it did not specifically target hand and finger function. Both P1 and P2 had improved during the previous 2.5 week trial (Hijmans et al 2011) and also in the four months between the trial interventions. This perhaps represents an improvement ceiling effect, particularly given that both participants were already relatively higher scorers on the FMA and well into the chronic phase of their stroke recovery. The gains of the previous trial and intervening period may represent the maximising of their recovery potential so that further significant recovery was less likely.

A limitation of this study may arise from the use of the combination of diaries of use and the IMI to investigate the construct of engagement in stroke rehabilitation, i.e. we assumed that 'engagement' is a combination of a psychological state (e.g. involvement, commitment, attachment), and a performance construct (e.g. effort, behaviour). Behavioural engagement implies or infers a motivational process and as such it suffers from a lack of precision, as behaviours are multi-determined. This has largely been identified from research into industrial and organisational psychology (Griffin et al 2008, Macey and Schneider 2008). In the area of rehabilitation and virtual reality platforms it is arguably important that research investigates the psychological factors that operate at the interface, especially when task specificity and intensity of practice are considered important to rehabilitation outcomes. Measuring components of engagement, plus the degree to which participants 'stick to task' is useful. This argument underpinned our use of diaries and the IMI, as the IMI measures domains of interest/enjoyment, value/usefulness, effort/importance, competence and choice. In the home environment of this trial, where professional (extrinsic) therapeutic input was absent, it could be reasonably expected that the IMI/diary results are representative of each participant's (intrinsic) engagement, although this interpretation is cautious. Confounding factors exist though, particularly individual expectations and timing. As the participants were all greater than 18 months post-stroke, it is possible that the 'window of opportunity' for further gains in function had actually significantly waned and been already taken up by the preceding 2.5 week trial (Hijmans et al 2011) and possibly the period between the two studies. This was perhaps counter to the expectations of the participants who thought that they would continue to improve at the same rate and may be relevant to the lack of correlation between the interest/enjoyment and the perceived choice scores obtained from P1 and P2.

To further investigate the effects of the intervention on motor function, this study would have benefitted from utilising the computer system to record real-time kinematics. This requires further development but has potential to reveal motor control variables during game play and may be able to reveal some of the motor control elements of hemiplegic arms during game play plus their change over time (e.g. range of movement, speed and smoothness).

In considering the DASH and FMA results together, an explanation for their contrasting results could be that of a "response shift phenomenon" (Sprangers and Schwartz 1999) where people may, as a result of the research process, re-evaluate the impact their stroke has had on their lives and re-scale their responses. Given these results, caution in interpreting the DASH is warranted and greater sample numbers are required in future home trials.

Active participation in rehabilitation programmes increases the benefit and effectiveness of therapy (Merians et al 2002). Unfortunately stroke rehabilitation, using arguably 'boring' conventional task interfaces, can produce a significant reduction in older adult motivation (Flores et al 2008). This trial shows that it is feasible to combine exercise therapy with computer-aided/VR games at home in a way that appears to interest and motivate users. Further, the diaries revealed that all participants consistently continued their rehabilitation sessions regularly each week for periods of similar duration or greater than that found in rehabilitation clinics, but without any therapist supervision or contact. The main aims of the study, feasibility and engagement, were thus achieved and suggest that the therapy was not 'boring'. Furthermore, because of the regularity of therapeutic game play, it is likely that a suitable intensity of exercise rehabilitation was achieved, although the actual number of repetitions were not recorded. Given that the motor function results were inconclusive though, future testing on a larger sample with less chronic stroke is needed.

The positive IMI results, in particular for interest/enjoyment and value/usefulness, suggest that the participants were successfully motivated by the computer games in combination with the CyWee-Z and handlebar to complete the bilateral therapy exercise regime asked of them. In future studies, pre-assessment of motivation and mood would be useful to initially establish background baselines. Although a range of games was offered, the low perceived choice of the participants may represent that the selection of games did not fully meet their needs or expectations. Two 100% value/usefulness ratings suggest though that the overall system was very positively perceived as being worthy. Overall, it is reasonable to interpret that the intervention motivated and engaged the participants to the extent that further research would be warranted, including comparing the efficacy of the intervention with treatment approaches that provide explicit extrinsic motivation and/or traditional therapy in outpatient or group settings. Without a control, it is not possible to know if the motivation provided by this home trial is truly any more effective than that provided by other interventions.

Although more emphasis in New Zealand is now being placed on primary healthcare and community stroke rehabilitation (Hale 2004), further stroke rehabilitation conducted in the community may add to caregiver stress. Technology, such as described in this paper, has the potential to augment community stroke rehabilitation and possibly lessen the burden on caregivers and community health clinicians, as once installed and set up, it can be used independently or with minimal assistance by many stroke-affected persons. In the future, automated monitoring systems (e.g. telerehabilitation, electronic diaries) could also be combined with the system described in this paper, where remote supervision and quantitative monitoring by clinicians could be provided. Rehabilitation could then be progressed via a more typical client-therapist relationship and provide greater specificity in exercise prescription, yet without the need for a therapist having to be physically present. Remote internet-based monitoring could have benefitted this study by providing richer data, such as actual number of repetitions per session, distance of arm travel, force and direction/accuracy.

When considering home and community based rehabilitation, social rehabilitation atmospheres are preferred by some people (Hale 2004, ILO, UNESCO and WHO 1994). The intervention described in this research could be provided as a component of community-based rehabilitation in group (social) environments, such as fitness gymnasiums or rest homes. It could also be linked into social media networks. These are additional areas for further research using the technology described in this paper.

CONCLUSIONS

This case series demonstrated that bilateral upper limb rehabilitation at home, using computer games played via a motion-based controller, is feasible, engages users for a duration considered necessary for rehabilitation to be effective, and offers potential for home or community-based rehabilitation. Although change in motor function was inconclusive, this study acted as a useful pilot for further research with larger samples into the efficacy of bilateral upper limb stroke rehabilitation, computer facilitated virtual reality and home stroke rehabilitation.

KEY POINTS

- Bilateral upper limb therapy for stroke rehabilitation using a motion-based controller (Cywee-Z) with computer games is feasible in an unsupervised home setting.
- Bilateral upper limb therapy using a motion-based controller and computer games motivates and engages users to exercise for up to 5.5 hours per week over 8 weeks.
- Further research into home therapy systems for upper limb stroke is justified.

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Appendix 1: Sample questions from the 32 question Intrinsic Motivation Inventory

IMI domain	Sample question
Interest/Enjoyment	'I thought this activity was quite enjoyable'
Perceived Choice	'I believe I had some choice about doing this activity'
Effort/Importance	'I put a lot of effort into this'
Perceived Competence	'I think I am pretty good at this activity'
Value/Usefulness	'I think that doing this activity is useful for my arm movement'