Online physiotherapy delivered using video games

Janet Eyre[1], Graham Morgan[2], Charlotte Lambden[1], Jian Shi[3], Javier Serradilla[3]
[1]Institute of Neuroscience, Newcastle University, UK, [2]Computing Science, Newcastle University, UK, [3]School of Mathematics and Statistics, Newcastle University, UK

Introduction

Musculoskeletal disorders and chronic neurological disorders, such as impairment following stroke, are the most common reasons for disability worldwide[1]. Physiotherapy provides effective treatment but is limited by financial constraints and staff availability. This no more true than in rural and remote Australia where the relative lack of work force capacity provides significant service provision challenges[2, 3] [4]. Service delivery to rural and remote communities is further complicated by the vast distances encountered because relatively small numbers of people in need are dispersed over large geographic areas, while allied health professionals tend to be located in large regional centres[5]. Thus, considerable time and distance costs are incurred by health professionals who travel to people in need, and by those people who travel to access services[6]. In recognition of these additional costs the *Federal Grants Commission provides a greater share of tax-generated funding to those jurisdictions with high percentages of rural/remote residents. There is a need to find new ways of delivering physiotherapy that enables the service to meet escalating demands from both urban and rural populations without parallel increases in costs or staff, and to provide equity of access for outreach therapy services to people living in rural and remote areas of Australia.*

Physiotherapist-directed rehabilitation programmes have been shown to be similarly effective, whether they are performed unsupervised at home or supervised by a physiotherapist in a clinic setting[7, 8]. Since the early 1980s, commercial “off-the-shelf “ *entertainment* video games have been deployed for therapy; a recent systematic review identified 1452 published articles using such games up until 2010, including 38 randomised controlled studies. Studies with high quality design reported significant therapeutic effects [9]. A Cochrane review in 2011 concluded that therapy delivered using *virtual reality, including virtual reality created within video games,* was of benefit for rehabilitation of motor function[10] and a recent meta-analysis concluded adult stroke survivors had significantly improved motor outcomes compared with conventional physiotherapy[11]. The success of video games for therapy can be attributed in large part to the increased engagement and motivation that well designed video games add to typically mundane and repetitive tasks associated with physical therapy[12]. Creating bespoke therapeutic videogames potentially enables the use of virtual reality to create controllable, interactive, multisensory, 3D environments, where therapeutic actions can be prescribed, motivated, captured and measured.

Our aims were to: (i) Determine if video games specifically designed to deliver a therapeutic programme would be played by patients without therapist supervision in their own homes; (2) Determine whether there was a dose response relationship, such that those playing the games for longest time had the greatest response to therapy; (3) Derive and validate a statistical model to predict a patient’s score on a validated clinical assessment from kinetic data of hand movements obtained during game play to enable remote monitoring of patient progress.

We chose to investigate these aims in relation to stroke rehabilitation, since stroke is a major global health problem[13, 14]. Sixteen million people worldwide suffer a stroke each year; more than 12 million survive. Stroke occurs predominantly in those aged over 60 and, since the world population is ageing significantly, the prevalence of stroke survivors is increasing and is estimated to reach 77 million by the year 2030. Hemiparesis, a detrimental consequence that many stroke survivors face, is the partial or complete paralysis of one side of the body from brain injury. It is remarkably prevalent occurring acutely in 80% of the cases[14]. Although it is known that recovery can be significantly improved with intense, repetitive and challenging rehabilitation [15] upper limb recovery is unacceptably poor, with persisting impairments in 50-70% of stroke survivors [16]. Limited resources, specifically lack of therapist time, are the main barriers to the provision of a suitably high dose of physiotherapy for effective recovery.

Subjects

Ethical approval was obtained from the National Research Ethics Committee for England and all work undertaken was in accordance with the Declaration of Helsinki. *Written, informed consent from all the subjects was obtained. The patients were recruited from Northeast England, from both urban conurbations and rural Northumbria, which has the lowest population density and most isolated populations in England.*

Eighty stroke survivors without significant cognitive or visual acuity impairment were recruited (see Table 1). A further inclusion criterion was that participants were able to move their affected limb against gravity. Since the games can be played either standing or sitting down, patients with a wide range of upper limb function were able to participate. None had previously played video games. Patients were stratified, a-priori, into two groups according to the expected amount of change in their upper limb functional ability throughout the duration of the study: The Acute Group (high change expected) who were recruited within 6 weeks of stroke onset and the Chronic Group (lower change expected), who were recruited 6 months or more after the onset of stroke.

Methods

Participants undertook online *therapy* unsupervised in their own home over 12 weeks. The therapy was delivered using a library of bespoke video games, professionally produced specifically for upper limb rehabilitation in which players participate in a number of Circus oriented activities. The games are controlled by commodity, commercially available game controllers produced by Sixense Entertainment (http://www.sixense.com/). The controllers provide continuous position and orientation information by using magnetic motion tracking. This is a well-established and researched technology and it is commonly used to measure 3D position in space[17]. The controllers return three-dimensional position data and nine-dimensional orientation data for each hand with a sampling frequency of 60 Hz[18].

To play the game participants must move as directed both to score points and to ensure successful completion of an activity. In Figure 1 we show a screen shot from the game, where a player is directed to carry out a specified upper body upper limb movement by an avatar (the character in the circle in the bottom right of the screen) while an activity unfolds, in this case trapeze.

There are 100 different control moves derived from expert therapy programmes so that progression through the games delivers a rehabilitative therapy programme. Players work their way through levels of difficulty as they progress through the games; the time patients spend performing the therapeutic control movements (not simply playing the game) is automatically recorded to estimate the dose of therapy. In addition the speed, fluency or smoothness, synchrony and accuracy of the movements is also estimated automatically [18].

Figure 1 Screen shot from theTrapeze game showing avatar instructing the move to be made

Protocol

Patients were taught how to play the video games at baseline by a *therapy assistant* and then asked to play the games unsupervised in their home each day for approximately thirty minutes over a 12 week period. Research assessments were made in the patient's own home when an occupational therapist undertook blinded clinical assessments of upper limb function including the Chedoke Arm and Hand Activity Inventory (CAHAI) [19] and the Upper Extremity Assessment (FMUEA) [20]. These assessments were made at baseline and then weekly for 4 weeks, followed by an assessment every 2 weeks for a further 6 weeks, giving 8 assessments in all.

Results

80 stroke survivors were recruited and their characteristics are summarised in Table 1.

Table 1

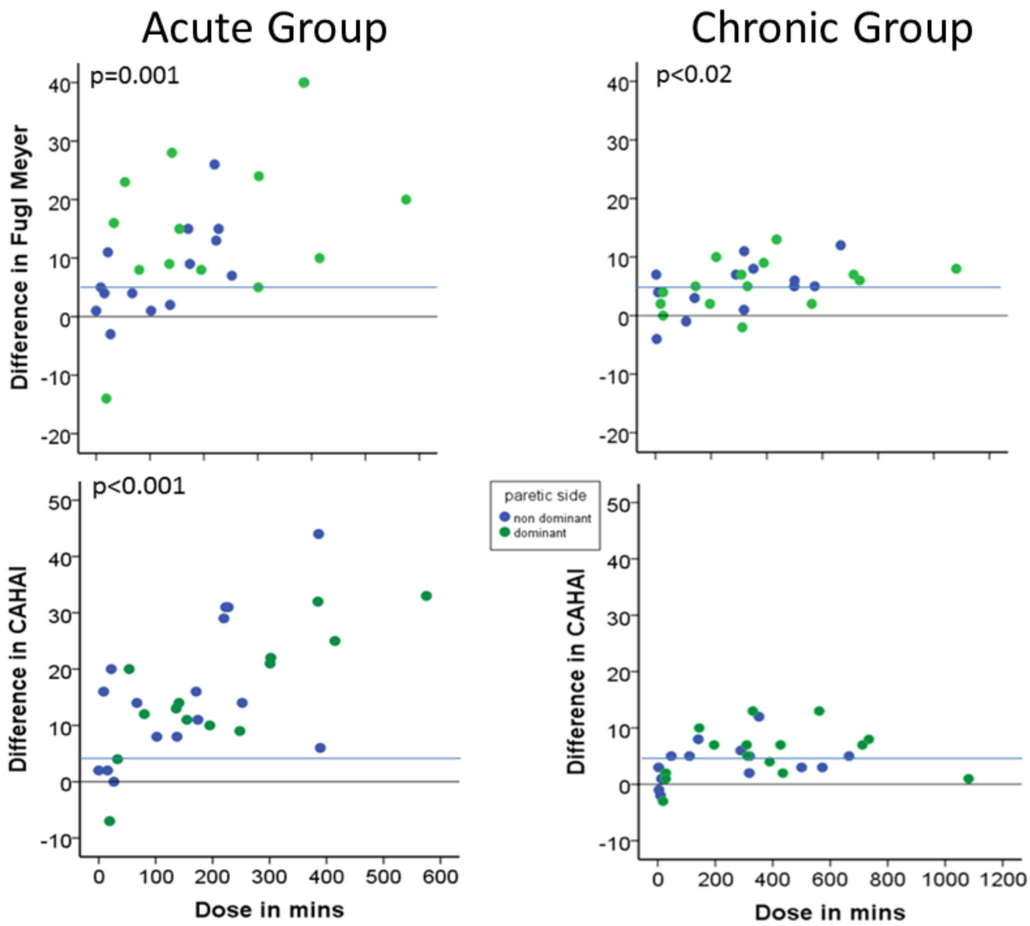
	Acute Mean ± SE	Chronic Mean ± SE
N	41	39
Age (y) Range	63.9±2.9 (33-84)	62.6±1.8 (43-81)
Sex (males)	28 (70%)	26 (70%)
Stroke of Dominant Hemisphere	21 (52%)	23 (60%)
Baseline Fugl Meyer Score Range	41.0±3.0 (12-59)	39.9±2.3 (13-60)
Baseline CAHAI Range	32.4±2.3 (11-51)	31.5 (11-58)
Time from stroke to therapy onset (weeks) Range	2.3±0.24 (0.9-4.8)	95.3±18.8 (27.3-506.1)
Total therapy time (dose in minutes)	182.2±34.7	336.9±50.6
Change in Fugl Meyer Score at 12 weeks	+13.7±2.5	+5.3±0.8
Change in CAHAI at 12 weeks	+16.6±2.5	+4.3±0.8

To examine Aims 1 and 2 a MANOVA was performed for Acute and Chronic Groups separately - *Dependent variables*: Change in FMUEA and CAHAI scores; *Fixed factors*: Sex, Hemisphere of stroke; *Covariates*: Therapy Dose - total time performing therapy moves, Baseline scores, Age, Time from stroke. There was a main effect for Therapy Dose for both Groups. For the Acute Group there were also main effects for Age and Time from Stroke (Table 2: Figure 2).

Table 2 MANOVA

	Group	df	F	Sig
Change in Fugl Meyer Upper Extremity Score				
Total Therapy Time (Dose)	Acute	1	17.44	0.001
	Chronic	1	4.22	0.049
Change in CAHAI				
Total Therapy Time (Dose)	Acute	1	30.94	<0.001
Time from stroke	Acute	1	8.12	0.012
Age	Acute	1	5.43	0.034

Figure 2 Difference in Upper Limb assessment scores between baseline and 12 week assessments in relation to the duration of time spent performing therapeutic moves

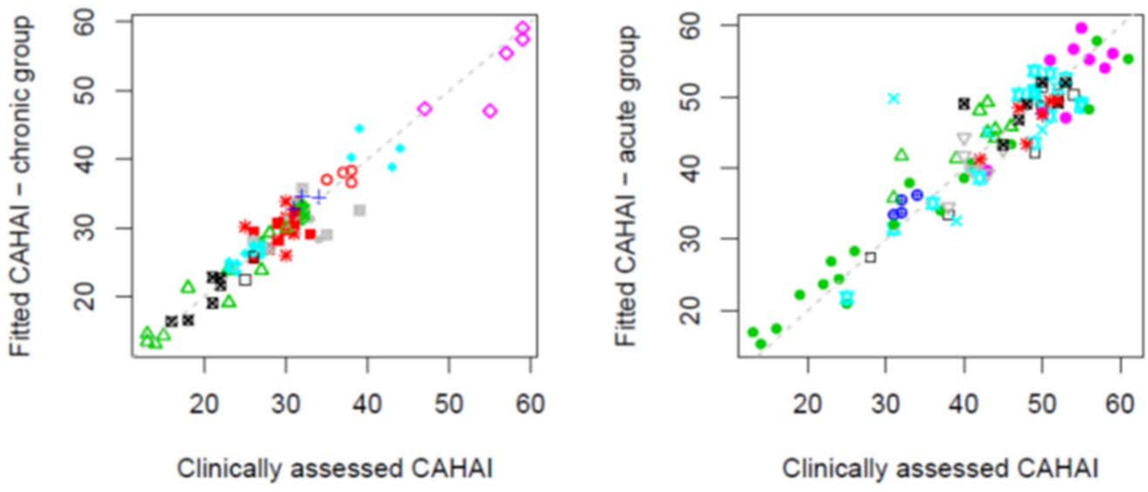


Statistical Model to predict CAHAI scores

Model derivation was undertaken on the first 39 subjects recruited. To account for the longitudinal nature of the data and the heterogeneity between stroke patients we fitted a linear mixed-effects model. The model has two distinct terms: a fixed-effects term and a random-effects term; this latter component allows for the modelling of the within-subject correlation. In addition, a variable selection approach was required to deal with the high correlation and the large numbers of covariates available; that process was done using best subsets regression [21] with the adjusted R2 as the optimization criterion.

The statistical model achieved accounted for 93% of the variability in the CAHAI-9 scores for the Chronic Group was 93 % and 86% for the Acute Group (Figure 3).The model error (Root Mean Square Error) was 2.32 for the Chronic Group and 4.02 for the Acute Group.

Figure 3 Clinically assessed CAHAI scores versus CAHAI scores derived from the statistical model



On the left, data for Chronic Group and on the right, data or the Acute Group.

Model output was also assessed using a convergent construct validation process between the clinically assessed scores and those derived from the statistical model. Cross-sectional validity (between-subjects correlation, bs-cor) is estimated by the weighted correlation coefficient between the subjects' means values. Longitudinal validity (within-subjects correlation, ws-cor) is estimated by the correlation between an individual's longitudinal measurements once differences between subjects are removed. The results are provided in Table 3 and show that the model derived CAHAI scores correlate significantly with the clinical assessment scores for both groups.

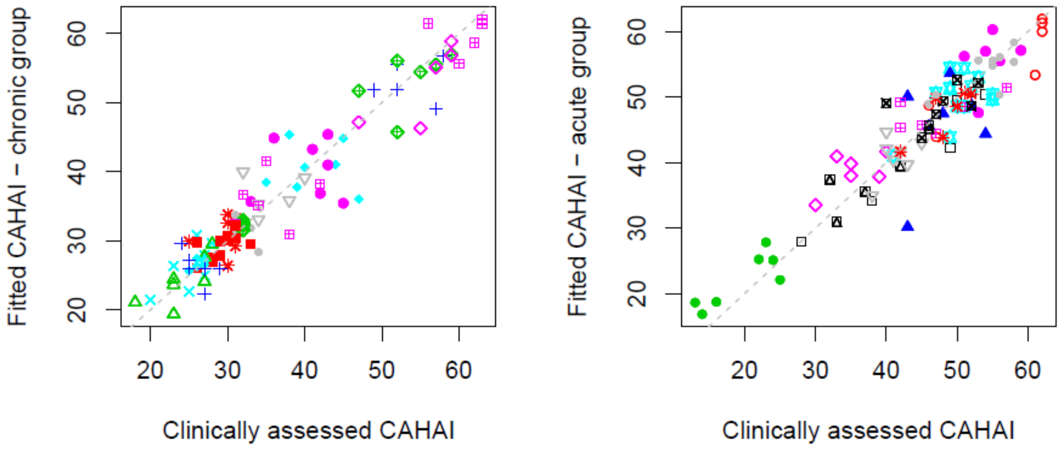
Table 3

	bs-cor	Sig	ws-cor	Sig
Chronic	0.996	p<0.001	0.732	p<0.001
Acute	0.976	p<0.001	0.768	P<0.001

Model validity

Model Validation was undertaken predicting CAHAI scores in the remaining 41 recruited participants, who had not been used to derive the statistical model (Figure 4). The error in predicting clinical CAHAI scores for these participants (Root Mean Square Error - RMSE) was 4.00 for the Chronic Group and 6.60 for the Acute Group. The cross-sectional and longitudinal validity are given in Table 4.

Figure 4: Validation data set



Clinically assessed CAHAI scores versus CAHAI scores derived from the statistical model. On the left, data for Chronic Group and on the right, data for the Acute Group.

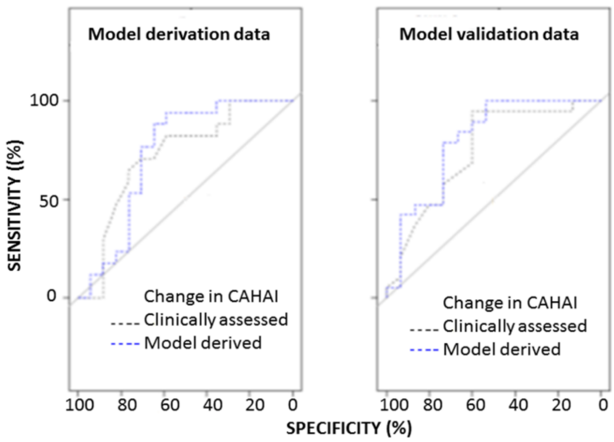
Table 4

	bs-cor	Sig	ws-cor	Sig
Chronic	0.981	p<0.001	0.295	p<0.01
Acute	0.810	P<0.001	0.62	p<0.001

Sensitivity to change

To determine if the CAHAI score derived from the statistical model was as sensitive to change as the clinically assessed CAHAI scores, the areas under the Receiver Operating Characteristic plots were estimated for each data set (Figure 5). The null hypothesis for the test is that there is no difference in the classification of patients into either Chronic or Acute groups using either the change in the clinically assessed CAHAI from baseline to 12 weeks or the change in the model derived CAHAI scores. There was no evidence against the null hypothesis (derivation data set: first 39 participants, p= 0.891; validation data set: last 41 participants, p= 0.595) and hence the model derived CAHAI scores are as sensitive to change as the clinically assessed CAHAI scores.

Figure 5 ROC curves on the left for model derivation data (first 39 participants) and the validation data set (last 41 participants) comparing the sensitivity and specificity of change in CAHAI score from baseline and 12 weeks into classify participants into Chronic and Acute groups



Discussion

This article describes a new approach to upper-limb function rehabilitation by using bespoke action video games and remote monitoring of patient progress. Patients aged up to 84 years played therapeutic video games, unsupervised in their own home. The time actually spent performing therapeutic control actions could be measured and this precise dose of therapy was found to be significantly correlated with improvement in upper limb function. Studies of experience-dependent synaptic-plasticity in nonhuman animals[22, 23] and humans[24] demonstrate that large quantities of practice lead to cortical reorganization and improved behavioural function. Similar studies link neural changes with recovery of function and learning in adults after stroke [25]. These data indicate that increased practice leads to greater skill, as long as practice is challenging, progressive, and skill based [25]. Meta-analyses also indicate a positive dose–response relationship for therapy after stroke in recovery of upper limb function [26-28].

Since we did not have a control group with no therapy, how much change is achieved by the game as opposed to natural recovery is not known. There are, however, factors which indicate a therapeutic effect of the video games over and above that expected from spontaneous recovery. First the most powerful predictors of upper limb recovery are baseline level of upper limb impairment and function [29-31]. The positive relationship between dose and recovery was independent of level of baseline impairment and baseline function for both the Chronic and the Acute patient groups, implying an effect over and above that of spontaneous recovery. Second, although as predicted there was a greater degree recovery of function in the Acute Group, a positive dose response relationship was also observed in the Chronic patients. The relationship was independent of the time since stroke, indicating benefit can be gained from playing therapeutic video games even several years after stroke (post-stroke times ranged from 0.5 to 9.7 years) when recovery over a 3 month period would not be expected as part of spontaneous recovery processes.

We also demonstrate, for the first time, that it is possible to automatically derive an assessment of upper limb function that is both as reliable and sensitive to change as a current gold standard used for clinical assessment and yet can be assessed remotely and relies only on low cost commodity technology. Similar models could be constructed for other commercially available controllers with high spatio-temporal resolution for measuring hand position and orientation, such as the Microsoft Kinetic. Furthermore we have shown online physiotherapy using video games can be delivered using commodity laptops which are already readily available to most households.

The delivery of the video games, collection of the data and estimation of the assessment scores were performed by a cloud based platform, accessed by simple website interfaces. The use of digital technology gives flexibility in scaling; services can easily be scaled up or down to meet evolving clinical needs, without adding to overheads or service costs. In addition since it can be implemented and patients can be monitored remotely, it has the potential to deliver high dose physiotherapy to remote rural areas of Australia (and rural Northumbria in Northeast England), providing equity of access to physiotherapy. Even in urban areas the capacity for remote monitoring and communication through a website means physiotherapists will be able to manage many more patients, while at the same time delivering higher intensity therapy to meet service guidelines.

It must be conceded, however, that many parts of remote Australia (and rural Northeast England) currently have slow internet connectivity making use of on-line and cloud technologies a potential major limitation for service delivery to many rural populations. We have incorporated several design features, in order to reduce this potential barrier for rural populations.

- Synchronous connectivity is not required between the cloud and the patient's laptop during therapy sessions. The game requires only the laptop to delivery therapy sessions and thus the speed of the game and its graphics are not dependent upon internet connectivity speed.
- After a therapy session preliminary data analysis is performed on the laptop to reduce the amount of data needing to be transferred to the cloud.
- At the end of a therapy session, transfer of data to the cloud occurs automatically whenever the next internet connection is established.

- ADSL, cable, fibre, satellite and wireless technologies can be utilised, since the speed of data transfer is not a critical feature.
- The patient facing and therapist facing websites have been designed to be both intuitive and simple so that they are quick to load even if there is low speed internet connectivity.
- Feedback from the therapist to the patient is also automatically transferred to the patient's laptop at the next internet connection and the date and time of this feedback is indicated to the patient.

Conclusion

We propose that online therapy is a means to greatly increase the dose and therefore efficacy of physiotherapy. We are not proposing that it is used to completely replace on to one sessions with a therapist, rather that online video games-based therapy would best be applied as a key component of a broader outreach model, where the physiotherapist does actually spend time face-to-face with the patient, but where this 'getting to know one another' then lends itself to more effective remotely controlled game-based activities and other modalities like tele-health. It doesn't have to be an all or nothing situation which either relies on a regular presence of the physiotherapist (hard to achieve) versus the physiotherapist only ever being remote to the patient.

Disclaimer

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Presenter

Professor Janet Eyre is Professor of Paediatric Neuroscience at Newcastle University in the UK. A previous Rhodes Scholar and Wellcome Senior Fellow in Clinical Science, she is an internationally recognised expert in brain plasticity following brain injury across the life span and its implications for rehabilitation. She currently leads a research program of £2.7 million into the clinical application of video games for online physiotherapy, enabling home-based-delivery of therapy with expert remote monitoring and management by therapists. She has been awarded the following for her work in Online Physiotherapy: The NHS Innovations North Bright Ideas in Health Award 2009; CELS Business for Life Awards—Partnership with the NHS 2010; The UnLtd and Higher Education Funding Council for England Entrepreneur Award 2010; Medical Futures Best Innovation to Improve Patient Care—Cardiovascular Innovation Award 2011; Medical Futures National Health Service Innovation of the Year Award 2012 presented by Professor Sir Bruce Keogh, NHS Medical Director for England.