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ABSTRACT

Background

A low cost, virtual reality system that translates movements of the hand, fingers and thumb into game play was designed to provide a flexible and motivating approach to increasing adherence to home based rehabilitation.

Objective

Effectiveness depends on adherence, so did patients use the intervention to the recommended level. If not, what reasons did they give?

Design

Prospective cohort study plus qualitative analysis of interviews.

Methods

17 patients recovering from stroke recruited to the intervention arm of a feasibility trial had the equipment left in their homes for eight weeks and were advised to use it three times a day for periods of no more than 20 minutes. Frequency and duration of use were automatically recorded. At the end of the intervention, participants were interviewed to determine barriers to using it in the recommended way.

Results

Duration of use and how many days they used the equipment are presented for the 13 participants who successfully started the intervention. These figures were highly variable and could fall far short of our recommendations. There was a weak ($p=0.053$) positive correlation between duration and baseline reported activities of daily living. Participants reported familiarity with technology and competing commitments as barriers to use although appreciated the flexibility of the intervention and found it motivating.

Limitations

The small sample size limits the conclusions that can be drawn.

Conclusions

Level of use is variable and can fall far short of recommendations. Competing commitments were a barrier to use of the equipment but participants reported that the intervention was flexible and

motivating. It will not suit everyone but some participants recorded high levels of use. Implications for practice are discussed.

INTRODUCTION

After surviving a stroke, many people fail to regain functional use of their impaired upper limb.[1] Both meta-analyses and systematic reviews have shown that early intensive[2], task specific [3] practice for a prolonged period of time[4] facilitates motor recovery. There are no clear recommendations on how much practice a patient should engage in either in terms of duration of rehabilitation or number of repetitions. Most available evidence is on duration.[5] A meta-analysis[2] concluded that therapy input should be augmented at least 16 hours within the first 6 months after stroke. However, reviewing studies where constraints were applied to the less affected arm and thus forcing patients to use the affected arm led the authors to suggest a benefit from a high dose over a shorter period of time, specifically 6 hours per day during 2 weeks (i.e. augmentation of 60 hours). They also reported that there was no ceiling effect for therapeutic intensity, beyond which no further response is observed.

In the UK, in view of the evidence, the National Clinical Guidelines for Stroke[6] recommend that patients are offered initially at least 45 minutes of each appropriate therapy that is required for a minimum of 5 days per week if they have the ability to participate, and where functional goals can be achieved (3.14.1). However, the results from a recent national audit suggest patients are receiving between a quarter and a half of this standard.[7] Even when patients do receive rehabilitation, the upper limb receives scant attention with a recent systematic review reporting the average time spent on upper limb activities during a session as 0.9-7.9 minutes.[8] On discharge less than half of the patients with a Modified Rankin Scale of 1 or above are referred for further rehabilitation.

Even if patients are sent home with exercises, adherence to treatment is poor: 50%–55% of patients with chronic medical conditions fail to adequately adhere to treatment regimens.[9] Clay and Hopps (2003)[10] suggest that one factor that contributes to non-adherence is the perception of treatment regimens as rigid and immutable. Their effectiveness is irrelevant if they exhaust patients' capabilities and motivation. Adherence could be improved if treatments are designed that are amenable or adaptable to more appropriately fit into the lifestyles and limitations of patients and their families.

One route through which this may be achieved is through the adoption of virtual reality and interactive video gaming which have emerged as new treatment approaches in stroke rehabilitation.[11] Interfacing virtual reality games with robotic arms[12] exploits the benefits of these latter systems which were found in a systematic review[13] to have significant improvement in upper limb motor function. However, their cost, location in a laboratory, hospital or health centre and requirement for specialist technical support limit their availability for most patients. The appearance of commercial gaming consoles such as the Wii and Kinect have led to their adoption by therapists in clinical settings.[14] These consoles have the advantages of mass acceptability, easily perceived feedback and most importantly affordability for unrestricted home use. However, the games are not specifically designed for therapeutic use and while some of the games encourage movements of the upper limb, neither the Wii nor the Kinect system captures the movement of the fingers. The more recently appearing Leap Motion cannot currently capture sufficient information about the position of the fingers to be useful in the rehabilitation of the hand.

We developed a home based system that employs infra red capture to translate the position of the hand, fingers and thumb into game play.[15] Three games with varying levels of challenge encourage repetitive movements of the hand that underpin activities of daily living (such as reaching, grasping, pointing, moving and manipulating objects). In line with the MRC Framework for Complex Interventions[16] a feasibility randomised control study was carried out in preparation for an evaluation of the effectiveness of the intervention.

This paper examines data collected on the 17 participants who were randomly allocated to the intervention to answer the following questions:

- How close to the recommended duration were participants using the intervention?
- How close to the recommended frequency were participants using the intervention?
- What barriers or facilitators did they report to using the intervention at the recommended duration and frequency?

METHODS

Design

A prospective cohort study, plus qualitative analysis of interviews with the intervention group, from a two group feasibility randomised control trial comparing the intervention with usual care.

Participants

For the feasibility study 29 participants were recruited who were aged 18 or over, with a confirmed diagnosis of stroke, were no longer receiving any other intensive rehabilitation (intermediate care, early supported discharge) and who still had residual upper limb dysfunction. Of the 17 participants who were allocated to the intervention group 9 were women and 8 were men. At the point of randomisation the group had a mean age of 59 years (SD 12.03, range 40–82 years); the median time since stroke onset was 22 weeks (range 6–178). All participants experienced disturbance of fine motor control. 9 had a right and 8 had a left upper limb paresis; the affected upper limb was dominant for 13 of the participants.

The virtual glove and games

The intervention was developed based on motor learning theory and aimed to increase the number of repetitions of functional movements, whilst providing games that are challenging with feedback on performance. This is because increasing repetitions alone is not sufficient to drive neuroplasticity[17], with shaping (small steps of increasing difficulty with immediate feedback on performance) also known to improve recovery [18].

The virtual glove consists of a hand-mounted power unit, with four infra red light emitting diodes (LEDs) mounted on the user's finger tips (see Figure 1). The LEDs are tracked using one or two Nintendo Wiimotes mounted by the PC on which the games are displayed to translate the location of the user's hand, fingers and thumb in 3D space. Games were produced especially for the project with the help of therapists and stroke patients. In order to play them, users have to perform the movements of reach to grasp, grasp and release, pronation and supination that are necessary to effect many activities of daily living.

Three games were developed in conjunction with users.[15] Spacerace required pronation and supination of the hand to guide a space craft through obstacles. Spongeball required the user to open their fist and extend their fingers in order to release a ball to hit a target. Balloonpop required a balloon to be grasped and popped by moving it to a pin protruding from the floor.

They were designed to be constantly challenging, with increasing levels of difficulty dependent on ability. This was to maximise motor learning and to keep the participants motivated to continue to use the system but to ensure that they can achieve some success. Difficulty was increased by greater movement being required to complete a task, an increase in the speed at which events occur and with which responses are required, or an increase in the precision required to complete a task. As the system works on detecting position of the fingers in the glove and not the movement of the wrist, elbow or shoulder or sitting posture, it was important that a therapist provided initial instruction and subsequent ongoing support and therefore reduce unwanted compensatory movements. Immediate feedback was given by participants' scores being displayed on the screen at the end of a game and a permanent visual display of their progress in terms of scores and levels played. A log of when the system is in use was stored on the computer as well as what games were being played and what scores the user obtained.

Intervention

Participants were randomly allocated to either the intervention group or the control group. Those participants in the intervention group had the virtual glove in their homes for a period of 8 weeks and were advised to try to build up to using the system for a maximum of 20 minutes 3 times a day for 8 weeks.

Outcome measures

For the feasibility trial these were: Wolf Motor Functions Test[19]; Nine-Hole Peg Test[20]; Motor Activity Log[21] and the Nottingham Extended Activities of Daily Living Scale.[22] For the intervention group, the frequency of use of the glove was collected by the software.

Procedure

Ethics approval was obtained from the local NHS Research Ethics Committee before potential participants were recruited from the community stroke teams. Informed consent was obtained and baseline assessments were collected during a home visit before the participant was randomly allocated to the intervention or control group. For those assigned to the intervention group, three procedures were put in place to encourage them to use the equipment at the recommended duration and frequency. First, considerable face to face support was provided. The physiotherapist or occupational therapist from the research team delivered and set up the equipment. Based on the participant's ability, the therapists drew up a sheet for each individual advising them what games to start with and at what level. The glove and games were demonstrated to the participant and their carer and they were then trained on how to use the equipment independently. The researcher then arranged to return to repeat this demonstration until they felt that the participant had understood how to use the glove or that there was a carer who understood how to use it. The researchers also provided phone support to check the participant had been able to use the equipment and to offer further visits to clarify any outstanding matters if required. After the initial setup and training period, a member of the team visited either weekly or fortnightly, depending on the level of support required, to check progress and retrieve data. Second, the participant was given a phone number on which a member of the research team could be contacted during working hours if they needed any advice or if the equipment failed. Third, they were provided with an instruction manual which included Frequently Asked Questions and troubleshooting tips.

After four weeks all participants were visited at home for completion of the outcome measures. At the end of the intervention, after the equipment had been collected, participants were invited to take part in a short semi-structured interview to determine their experience of using the glove, barriers to using it in the recommended way and to the recommended levels. Interviews were conducted by a member of the research team with whom the participants were already familiar and audio recorded. All participants still in the study completed outcome measures at eight weeks post randomisation with a blinded assessor.

Analysis

Game data were collated from individual html files into Excel spreadsheets in order to produce individual participant data on duration of use, number of days on which the glove was used and number of times the glove was used each day. These data were then transferred to SPSS v20 for summarising. Interviews were transcribed verbatim and anonymised before each one was verified for accuracy by KT and analysed using thematic analysis a method for identifying and reporting patterns or themes within data.[23] All transcripts were read by CS and PJS , identifying issues relevant to general rehabilitation and those specific to our intervention before comparing and agreeing initial codes from the first five transcripts and collating codes into potential themes. Remaining transcripts were then coded independently and the themes jointly identified were reviewed by KT to maximise validity. The full analysis is reported elsewhere. Only those issues that may explain level of use of the intervention are summarised here.

RESULTS

Of the 17 participants randomly allocated to the intervention group, 4 did not complete sufficient training to start the intervention. The reasons for this were: family issues (1); intervention 'wasn't his thing' (1); could not complete training due to arm pain (1); arm pain and severe aphasia (1). Midpoint outcome measures were collected at four weeks on 12 participants, as one had already stopped using the glove, having experienced a seizure. Of these 12, 9 completed outcome measures after eight weeks. The reasons given by those who dropped out were: illness (1); ill family member (1); going on extended holiday so only had 4 week intervention (1). Table 1 shows the characteristics of the 13 who successfully started the intervention.

How close to the recommended duration were participants using the glove?

In order to answer this question, two sets of data were examined: hours of use and days on which the glove was used. For each participant who successfully started the intervention (N = 13), the percentage of use of the glove was calculated. As the time the glove was present in participants' homes varied, for example one went on holiday after 4 weeks, the hours of use were therefore converted to a percentage of the maximum hours they would have used it if they followed the recommendation of 20 minutes 3 times a day while it was in their home. Similarly, number of days on which they used the glove was converted to a percentage of the number of days the glove was in their home (see Table 1 and Figure 2).

There is considerable variation both in terms of duration of use and the number of days used. For example, P2 used the glove for only 1.46 % of recommended duration while P9 used it for 70% of expected duration. Similarly, percentage of days used ranged from 10% to 100%. In an attempt to identify potential predictive factors, use was correlated with age and baseline values of outcome measures but only the correlation between percentage duration and NEADL (rho = .661, p = 0.053) approached significance.

If participants were not using the equipment every day, how close to the recommended hour a day were they using it on the days when they did play? Figure 3 shows the median daily duration of use in minutes on days when the equipment was in use together with minimum, first quartile, median, third quartile, and maximum duration. Even for the participant with the highest use (P9) the median duration is less than 60 minutes although the huge variation and maximum value indicate that there were days where use exceeded 90 minutes and the third quartile indicates that on approximately a quarter of days use exceeded the recommendation.

How close to the recommended frequency were participants using the glove?

We recommended that participants used the glove three times a day. When calculating the number of times the glove was used, we defined a time or session as a period of use whose onset was more than 20 minutes after the last time the glove was used and whose cessation was more than 20 minutes before the next time of use. Figure 4 shows for each of the 13 participants the number of days on which they used it once, the number of days they used it twice, three times and four or more times.

Only 7 participants ever used the glove three times a day but all participants had days where they used it twice. Of note is that for 5 participants there were days when they used the glove four or more times, a frequency which exceeded our recommendation.

What barriers or facilitators did they report to using the glove at the recommended duration and frequency?

After the glove had been collected from participants' homes, 11 participants volunteered to be interviewed. Eight of these had completed eight week outcome measures and three had dropped out before completing the eight week outcome measures. Thematic analysis of interviews identified several explanations for the low level of use of the glove (barriers) as well as aspects that encouraged them to play (facilitators).

Barriers to use

These included technical issues; dependence; health problems; competing commitments and return to pre-stroke life.

Technical issues that arose due to the glove being a prototype, could restrict use. For example, the glove could be disrupted by bright sunlight or excessive infra red emission from other equipment in the participant's home. P4 reported on a few occasions that these made her want to throw the computer out of the window. Although participants had our phone number they did not always contact us for assistance when experiencing technical issues. For instance, P13 reported that when she could not get the glove to successfully work, she would sit in front of the computer and simulate the hand movements that she would make when actually playing the games, as she did not want to miss a session.

Technical confidence and experience if low, limited use of the equipment . P4 reported that sometimes she spent more time setting up than playing. That led her to prefer just one session a day: *"Yes, I got into it quickly towards the end, but at the beginning it seemed to take ages to get organised"*. However, if the participant's previous use of computers had involved frequent game playing, the games were likely to become boring: "*I started to sort of lose interest a little bit, I think. But I think that was more to do with I'm used to playing on computers and I found that the games were a bit repetitive for me"* (P8).

Dependence on someone to help with equipment could be a barrier to use. For example, P4 could not change the batteries in the Wiimote on her own. This meant that she had to call the research team to change them for her unless her son was visiting. For P24: *"if she (my daughter) wasn't here, if she was at work I'd used it later in the day when she came home"*.

Health problems. Several participants experienced episodes of ill health such as flu which prevented them from using the glove. A sub theme within this was fatigue as many people recovering from stroke experience periods of disabling fatigue that require periods of rest throughout the day "in my first four months I was really a bit tired every day, I don't think I'd have had the chance to do that (use the glove)" (P9). A second sub theme was mood: one participant mentioned the barrier of periods of depression that can occur during recovery from stroke: "because you do get the mood swings with strokes. You might get them on a down day and then just think, oh what the hell" (P3).

Competing commitments such as looking after grandchildren could prevent participants using the glove: *"And what time the family came, if the family came just when I had started it – I had to then leave it"* (P4). Some participants had arranged private therapy sessions: *"Yeah well, because there's so much more – you know, you've got your physio to fit in"* (P3), and there were also less demanding activities: *"I admit it depended what was on the telly"* (P4).

Return to pre-stroke life Inevitably as participants recovered they wanted to return to their pre-stroke life especially if they were mobile. This included returning to work, going on holiday, driving or hobbies*: "I've got my allotments to do, there's obviously going out shopping and like trying to fit round the rest of your day"* (P3).

Facilitators of use

These included the flexibility of the intervention; its motivating qualities; alleviation of boredom; belief in its therapeutic nature and family support.

The flexibility of the intervention was appreciated by participants. One participant said: *"Whereas with a computer, you could say four o'clock/five o'clock, if you felt all right, you could do it sort of any time you wanted to. You're not set to a time all the time, which was quite good"* (P8). Another said *"I'll put the kettle on, while I'm waiting for the kettle to boil I can have a play with it, or, you know, I'm doing dinner, while the dinner's cooking I'll have a play with the computer"* (P3).

Finding games motivating. The immersive nature of computer games has been long recognised as an explanation why some young people play them for long periods and our games shared that characteristic for some participants: *"You don't always know how much you're on there for. It's quite addictive in some ways"* (P23). One reason for this was the competitive nature of the games: *"Yeah well I was trying to do that, beat the score from previous"* (P24).

Alleviation of boredom could facilitate use: *"While when I got bored I just used it"* (P24).

Belief in its therapeutic nature: *"because it helps – well, it helps you a lot in your movement. First and fore, with the position, you know, then you enjoy the games"* (P9).

Family support was crucial: *"My granddaughter used to play the balloon pop and encouraged me. I mean, obviously she got fantastic scores that I wouldn't be able to achieve, but I was so there, wanting to get as much as I could. It's quite - It's good to have other people to play with you because you said, you know, that we could set her up, and we did"* (P23).

DISCUSSION

Performance data collected by the software showed that for those who did, the duration of use and on how many days they used the glove were highly variable and could fall far short of our recommendations. The recorded figures are an underestimate as they do not take account of the period in which participants were following our advice to build up to the recommended level of use. However, our recommendations were not based on hard evidence and were a compromise between results from systematic reviews on duration rather than frequency of making a particular movement, and what pilot work indicated would be practical for participants to achieve and not too demotivating. We also wanted to discourage participants from prolonged use to avoid fatigue or the development of side effects[24] before we could visit to check on whether they were continuing to use the glove without causing fatigue or shoulder pain. As a dose response relationship has been shown for practice and recovery[2] any increase in activity is beneficial.

Factors that might be associated with variation in use can be suggested from an examination of both the participant characteristics and the themes emerging from the interview analysis. While not a direct measure of upper limb ability, the weak relationship with reported activities of daily living suggests that higher levels of ability to care for oneself are associated with more use of the glove/games. This may be because higher levels of activities of daily living are a proxy for either the ability to set up the equipment or for having more time for the intervention due to activities of daily living being more quickly completed. There was no correlation with age: two of those who used it the most were women over 70 suggesting that age is not necessarily a barrier.

Of the explanations that emerged from the interviews, some would apply to any home based, self-managed therapy, for example, illness, other commitments and getting back to pre-stroke life. Others were specific to this particular intervention for example, being dependent on someone to help with set up of the equipment and computer literacy. If someone has had little experience with computers before their stroke, this skill may be more vulnerable to disruption through the stroke or lack of use. However more and more people now use computers and smart phones and those now at retiring age, unlike their predecessors, are more likely to have used computers in the workplace. So as the population become more computer literate this is less likely to be a barrier.

The rationale for developing the intervention had been to provide a flexible[10] and motivating way of exercising the upper limb, and analysis of interviews indicated that participants appreciated the flexibility of the intervention and its ability to motivate them to use it more. Some of the less impaired participants were already trying to get back to work or other activities they had pursued before their stroke, thus limiting the time they had for the intervention. Jones et al[25] state that self-management programmes need to reflect the diversity of individual responses and needs but also that "some individuals may not have the capacity to take on responsibility for their own health at a time when they may be still learning to adjust to losses and challenges" (p260). Our intervention was introduced at a time when we hoped that participants had managed some of these adjustments. However the diversity that Jones et al mention must also take account of the different rate at which people recover post stroke and start to engage in competing activities. Interestingly, none of the 13 mentioned physical issues as a barrier.

Unlike other unsupervised home based self-managed therapies, this study was able to collect an accurate record of when participants did their therapy. If they had used their unaffected hand or let someone else play without entering the "guest" user code, their record of play would have looked very different so we were able to check for the presence of abnormal patterns of use. What we do not know is how much use these participants would have made of an alternative, non-technological method of unsupervised rehabilitation. Self report[9] indicates that it would be low. The glove was left with participants for up to eight weeks which is a longer exposure than many upper limb interventions (see for example [1;26]) but is a long time to ask people to comply especially if they are trying to return to their pre-stroke life.

This intervention shows promise in being the flexible and motivating approach required to provide the opportunities for rehabilitation required to regain optimal functioning of the upper limb post stroke. However, it would be regrettable if this type of approach was seen as an alternative to the hands-on involvement of a therapist rather than supplementing the limited amount of time therapists have available for each patient. As this was a research study, participants received a considerable amount of support from the research team which suggests that as a therapeutic intervention this would still need input from a therapist to be successful. Future research is required to identify what factors make it more likely patients will use an unsupervised technical home based therapy and to explore how to increase use in those who are less likely to use it.

CONCLUSIONS

Performance data collected by the software from thirteen participants allocated to the intervention group in a feasibility RCT indicate just how variable was the use of our home based intervention for rehabilitation of the upper limb and how far short of the recommendations use was. Interviews with participants at the end of the intervention indicated that barriers to recommended use could be specific to the technology but could also apply to other unsupervised home based therapy. However, participants found it flexible and motivating indicating its potential for improving the opportunity for rehabilitation of the upper limb following stroke.

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Table 1. ***Characteristics of the 13 participants who successfully started the intervention. The final column shows the predominant explanations for level of use in terms of themes that arose from analysis of the interviews. For a description of the themes see text.***

Participant	Age / gender	Time since stroke (wks)	WMFT[1] baseline	MAL[2] No activities baseline	NEADL[3] baseline	Dominant side affected	Percentage of recommended duration of use	Percentage of recommended days used	Themes from analysis related to adherence
P1	63/F	16	3.60	9	22	yes	3.42	17.24	Not available for interview
P2	82/M	15	6.12	12	12	yes	1.46	10.77	Recurring illness over intervention duration[4]
P3	53/M	17	1.48	23	59	no	16.53	70.59	Competing commitments; return to pre-stroke life; technical problems, health (low mood); flexibility of intervention.
P4	79/F	9	2.22	22	44	yes	20.86	77.19	Technical issues; low technical confidence; dependence; competin

									g commitm ents.

P8	54/M	16	1.53	15	37	yes	4.64	15.79	Technical issues; high technical confidence and experience.
P9	53/F	19	2.19	28	63	yes	70.60	96.67	Went on holiday after 4 weeks of the intervention; health (fatigue); belief in its therapeutic nature.
P13	76/F	178	2.00	19	44	yes	58.84	100.00	Technical issues; competing commitments; belief in its therapeutic nature; flexibility
P17	58/F	30	1.79	21	32	yes	6.23	29.82	Fatigue; technical issues; competing commitments; family support; belief in its therapeutic nature.
P22	68/M	22	3.97	10	38	no	5.99	17.86	Return to pre-stroke life; health problems.

P23	57/F	54	16.15	8	34	yes	20.68	80.00	Health problems; found games motivating; family support
P24	55/M	22	1.63	17	40	no	6.75	31.48	Dependence; found games motivating; alleviation of boredom
P26	40/F	23	4.16	22	45	yes	7.76	29.63	Ill health of family member; return to pre-stroke life; other commitments
P27	41/F	6	2.65	23	31	yes	3.60	22.22	Not available for interview as experienced a further stroke.

[1]Wolf Motor Function Test results are expressed as the median completion time per item in seconds: the higher the score the longer it takes the participants to carry out the task
[2]Motor Activity Log number of activities the participant can attempt with their affected hand ranges from 0 to 29
[3]Nottingham Extended Activities of Daily Living scores range from 0 to 66 with higher scores indicating greater independence
[4]P1 was unavailable for interview post intervention but field notes record that they experienced long periods of illness during the time the equipment was in their home

Figure 1. *The Virtual Glove*

Figure 2. *Percentage of recommended use expressed in terms of duration and numbers of days for each of thirteen participants*

Figure 3. *Daily duration of use in hours and minutes on days that glove was in use for each of thirteen participants*

Figure 4. *Number of days participants did not use the glove, used the glove once, twice, three times and four or more times a day.*

Figure 2.

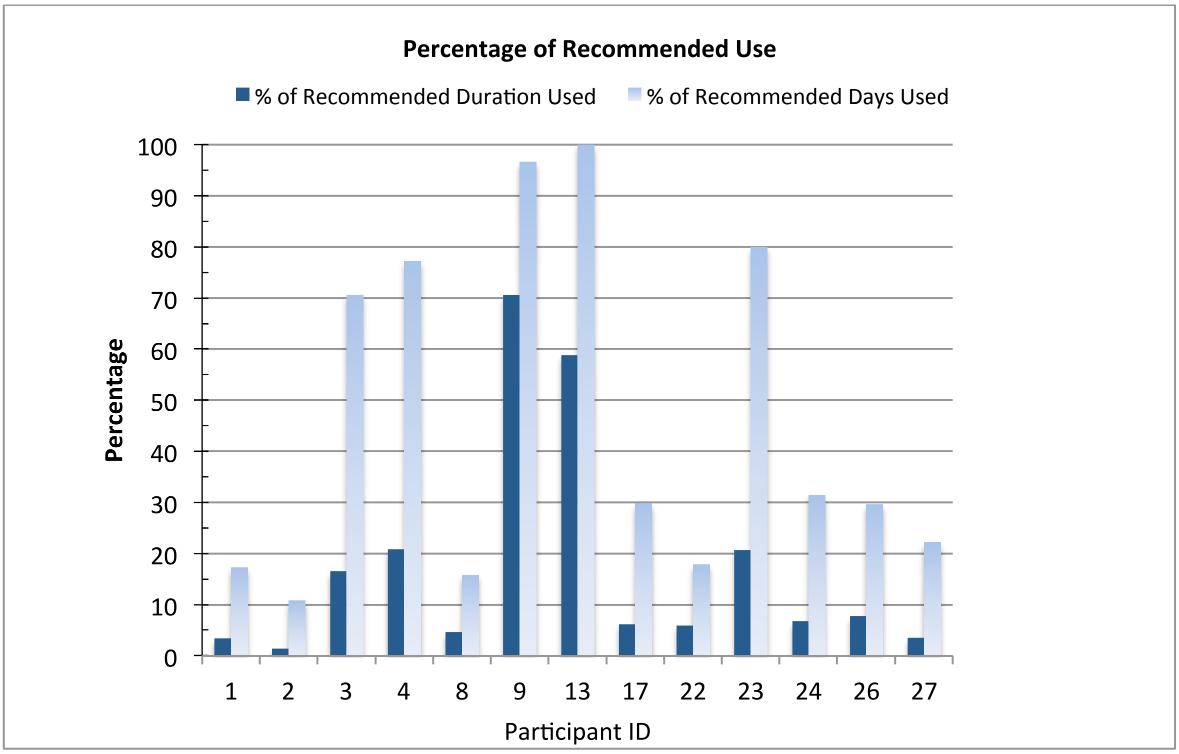


Figure 3.

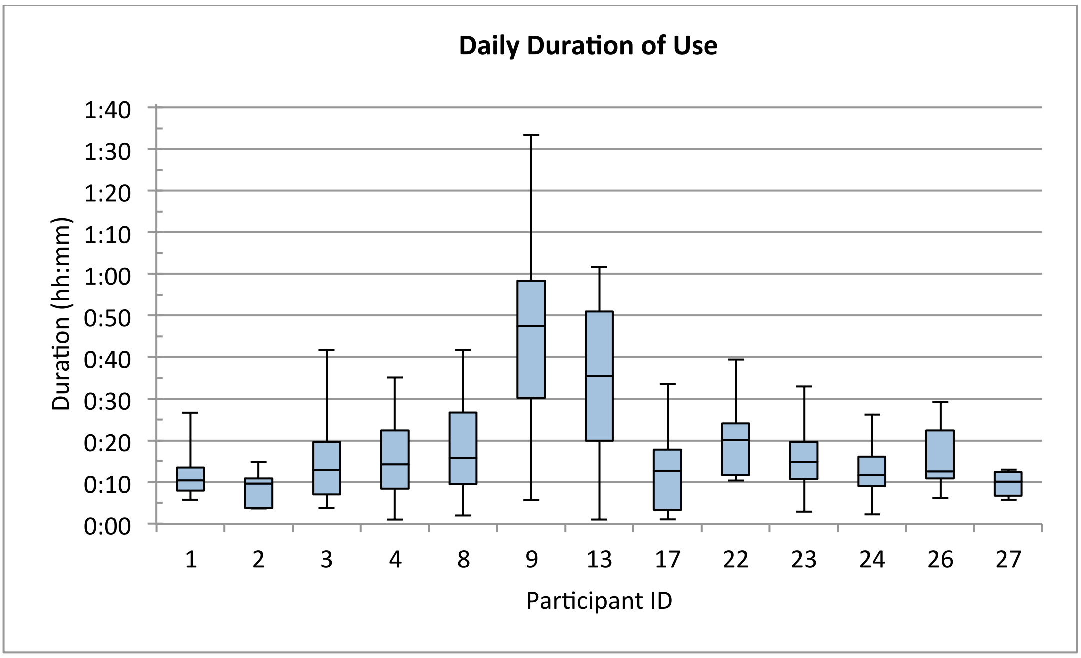
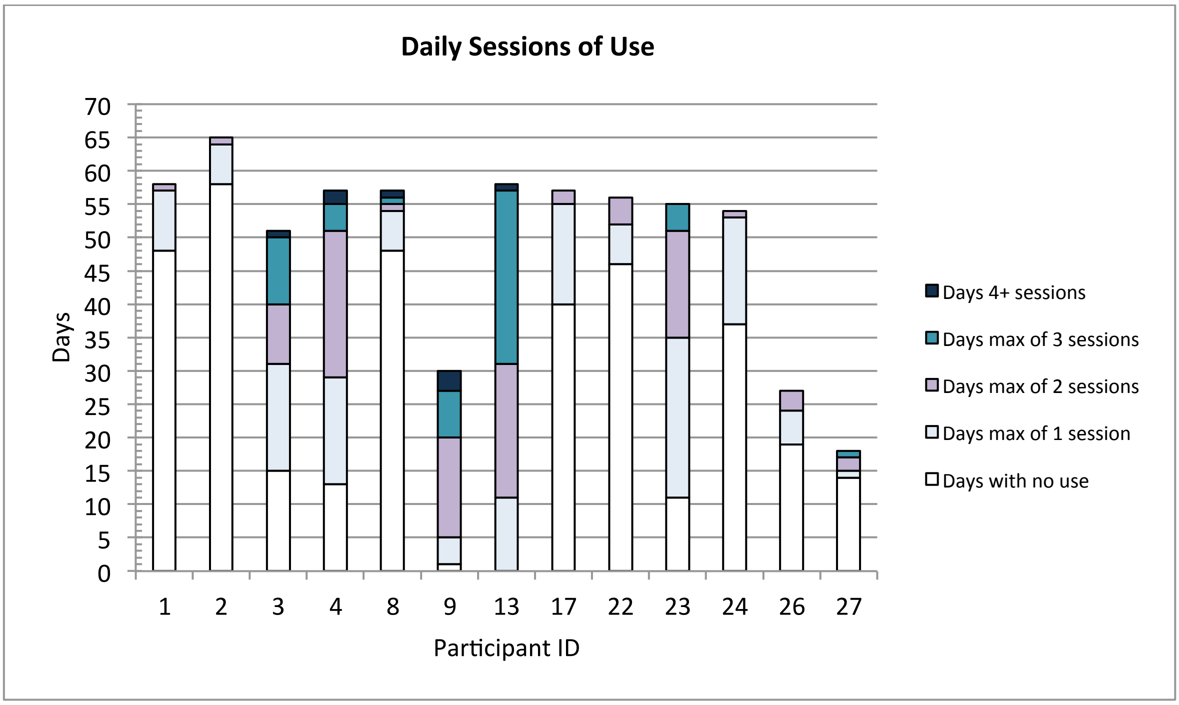


Figure 4.


Daily Sessions of Use
Days
Participant ID
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1
2
3
4
8
9
13
17
22
23
24
26
27
Days 4+ sessions
Days max of 3 sessions
Days max of 2 sessions
Days max of 1 session
Days with no use

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Patients' Use of a Home-Based Virtual Reality System to Provide Rehabilitation of the Upper Limb Following Stroke

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