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Developing and testing a telerehabilitation system for people following stroke: issues of usability

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This paper describes user testing of a technological system which enables stroke survivors to independently undertake rehabilitation exercises at home. The prototype is based on advanced movement sensors which are worn by the user when performing prescribed exercises. Sensor data are transmitted to a computer which displays the user's movements and progress. The number and type of sensors, methods of attaching them to the user's body in the correct locations, the type of computer screen and the input devices were changed and refined as the project progressed in response to feedback from people with stroke, their carers and physiotherapists. Home-based testing of the system highlighted usability issues concerned with the appropriateness and acceptability of the equipment in domestic settings, the sensors and methods of attachment, and use of, and interpretation of the screen presentation. Users required education as well as support throughout the testing period. Increasing sophistication of the technological aspects of the system over time resolved some usability issues but also created others, as did meeting the aims of improved clinical utility. The interplay between technology development, clinical utility and usability must be taken into account for devices to be successfully developed for practice.

Keywords: human factors; user evaluation; user observation; design strategy

1. Background

Telerehabilitation devices are socio-technical systems in that they include both human components (the end-users and health practitioners) and technological components, with the system being contextualised within the environment where the technology will be used (Brennan and Barker 2008). Consequently, the development, testing and mainstreaming of telerehabilitation devices present engineers, HCI specialists, clinical researchers and industry with significant challenges (Diamond 2003).

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Firstly, there is the fundamental research necessary to ensure that any prototype device has the necessary functionality and accuracy (clinical utility). This means ensuring that the technology can deliver equivalent standards of practice to those provided through traditional methods of service delivery, taking into account the specific rehabilitative requirements of the user group for whom the technology is intended.

Secondly, the ultimate value of any telerehabilitation device will be determined by prior perceptions, and actual experience of, using the device, with usability referring to the extent to which an interface is considered to be accessible, acceptable, robust and comprehendible by all who interact with it.

Thirdly, the mainstreaming and commissioning of these devices and their confident use by health practitioners necessitates evidence of effectiveness from robust clinical evaluation, which ideally includes an economic component.

Finally, the successful adoption of technologies within established health service systems requires the workforce to be trained and supported to work in different ways; thus the organisational context within which the technology is used is significant.

The value of technology to promote delivery of health services including rehabilitation is acknowledged by policy-makers (Royal Society 2006, Darzi 2008). However, existing published evidence on telerehabilitation is largely focused upon the technical features of devices and reports of pilots of clinical utility, e.g. the studies of Tousignant *et al*. (2006), Hoenig *et al*. (2006), and Reinkensmeyer *et al*. (2002). Usability is often set aside or is low priority even though evidence demonstrates the critical role it plays in determining acceptance of other more established health technologies. For example, evidence regarding the factors known to promote acceptance or rejection of in-home use of assistive devices include acceptability (including size and aesthetic appeal), ease of use, space required for storage and reliability (Mountain 2004). Consequently, usability of telerehabilitation devices is likely to be of equivalent importance to clinical effectiveness in determining adoption in practice (Wilson *et al*. 2007).

2. The research programme

From 2003, the EPSRC SMART Consortium (www.thesmartconsortium.org) has been involved in research to develop and test a prototype telerehabilitation device for therapeutically prescribed stroke rehabilitation for the upper limb. A simultaneous body of research into remote rehabilitation for upper limb stroke rehabilitation was undertaken in the Netherlands and Germany by Philips R&D. A strategic partnership between the SMART Consortium and Philips from 2006 onwards led to significant improvements in the technological capabilities of the prototype.

Stroke was the selected clinical condition due to the significant incidence of stroke globally (World Health Organisation 2004) and the high levels of resultant disability in stroke survivors (Stroke Association 2001). The range of impairments an individual might experience following stroke is wide ranging and can include hemiparesis, cognitive deficits and problems comprehending and responding to verbal and/or written communication. Long-term rehabilitation is instrumental in reducing disability following stroke with national guidelines advocating that all stroke patients should receive specialist rehabilitation to meet their needs (Intercollegiate Stroke Working Party 2008). However, needs such as the requirement for continuing rehabilitation can be neglected in the transition between acute care and return to the community (Cunningham 2003).

From the commencement of the research programme, the relationship between the human and technology factors had to be optimised and the user–technology interface made usable and intuitive. This necessitated the involvement of significant users, namely stroke survivors (subsequently referred to as end-users), family carers and stroke physiotherapists at all stages of device development and testing.

Table 1. Summary of user involvement in the research programme.

Aspect under investigation	Therapy involvement	Dates	User/family carer involvement	Dates
Initial design requirements	Focus group: eight therapists	10/04	Four focus groups: eight stroke survivors and seven carers	6/04
Sensor attachments. Decision support interface	Focus group: five therapists	5/05	Series of three workshops with 10 users and six carers (expert users)	10–11/06
Usability testing of system software	Demonstration: three therapists	9/06	21 tests in stroke clubs and in a stroke rehabilitation clinic	6–8/06
Presentation of the first working prototype including therapy content	Focus group: five therapists	12/06		
First home testing of wired prototype			Two week home tests: two male users (including one expert user)	12/06
			Two week home tests: two female users	3–4/07
Presentation of screen feedback	Demonstration video of home testing: two therapists	2/07		
Additional therapy content	Postal survey to therapists on most commonly prescribed exercises: 28 replies	4/07		
New wireless prototype and screen options			Individual trials of new prototype in university laboratory with four previous home testers	6/07
Home testing of wireless prototype			Two week home tests: four male users (including one expert user)	9–11/07

This paper describes the home-based testing of the first and second prototype with end-users and their family carers with a focus upon system usability. The entire programme of user involvement is summarised in Table 1 with the results regarding the clinical utility of the device being reported in a forthcoming paper.

All users described in this paper were recruited through a local private physiotherapy clinic and a local carers group. All physiotherapists were recruited through local networks of the professional body (Chartered Society of Physiotherapists). Ethical approval was obtained from Sheffield Hallam University.

The complexity of the overall research programme was difficult for end-users to comprehend. Therefore in the early stages of the research, it proved beneficial to maintain the same group of stroke survivors (referred to as expert users) who became highly familiar with the research and were able to make critical observations. However, as testing of the integrated prototype progressed, other volunteers were recruited who had not been previously exposed to the equipment so that a more generalised view was obtained.

3. Identification of initial design requirements

Initial work undertaken with therapists, end-users and their carers to identify a design specification confirmed that any technological device for stroke rehabilitation should be compact, simple to operate (and maintain), usable by people impaired by stroke (preferably without the help of the carer), available alongside the work of health professionals (i.e. not replace them) and able to give encouraging feedback to patients (Mountain *et al*. 2006). These principles were aimed for in the development of the prototype.

3.1. *System architecture*

The first prototype device incorporated two inertia sensors (comprising accelerometers, magnetometer and gyroscope technology) worn on the upper arm and forearm to record kinematic data from the users undertaking a functional activity. In addition to motion-tracking sensors and attachments, the system included a base station unit (media PC) and a web-server unit (Zheng *et al*. 2006).

The system architecture (Figure 1) demonstrates how it is envisaged that healthcare professionals will be enabled to monitor and assess user progress with their rehabilitation remotely via the internet (this aspect of the system is still in development).

On the basis of cost, size and performance, wired MTX sensors (Xsens Dynamics Technologies, The Netherlands) were considered the most appropriate for the early prototyping with the realisation that rapid system development would result in more sophisticated technology over time (Zheng *et al*. 2005). An iterative design process was adopted in partnership with designers to devise optimal methods of sensor attachment (Mountain *et al*. 2006). The preferred option was a simple arm band and a wrist band, designed to be donned and adjusted with one hand, as shown in Figure 2.

Once the sensors are attached in the correct locations and the equipment is assembled as shown in Figure 2, the user waits for confirmation that the system is ready and then undertakes an exercise

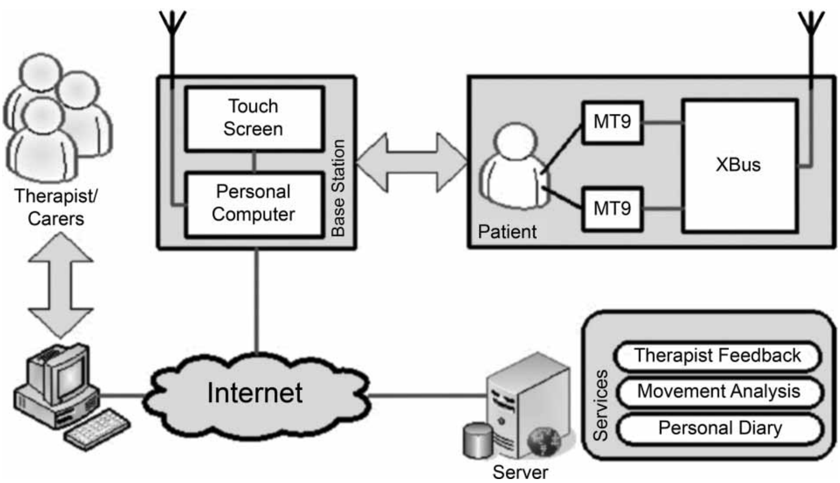

Figure 1. System architecture.

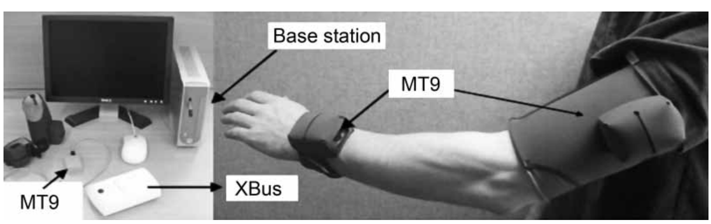

Figure 2. Initial prototype.

from the library of interventions, e.g. reach out and stretch the arm and then return. They undertake a series of repetitions before receiving feedback on quality of movement and progress from the decision support interface.

The decision support interface (Figure 3) is designed to enable recording and playback using a manikin presentation which includes a zoom function display of a side, frontal or top-down angle of observation. Display can also be provided on a split screen (showing a manikin completing a target movement with the user movement given on a second manikin above) as shown in Figure 4, or on a ghost mode (with a superimposed image showing a target movement and the user's own movement on the same manikin). Additionally, there are facilities to provide feedback through charts and tabulated data. A specific requirement was that people with little or no computer

Figure 3. Home page of decision support interface.

Figure 4. Screen feedback.

experience should be able to both operate and understand the screen. The first software prototype was tested by users in June 2006 with a range of issues being identified, e.g. challenges using computer and keyboard, ability to understand how to operate the screen and how to interpret computer feedback (Wilson *et al*. 2007).

4. Home testing of the first integrated prototype

Following several iterative changes to the software, the integrated prototype was assembled and four volunteers were recruited to test the system in their own homes (Table 2). Three had experienced a right-sided stroke resulting in left hemiplegia. Mrs Watson, the fourth user had a right hemiplegia as a result of a left-sided stroke. Also, Mrs Watson was the only volunteer without a co-resident carer; she had a paid carer to assist with her youngest child. All physiotherapy was suspended during the period of testing.

The researchers conducted four home visits to each participant throughout the testing period, and were also available by phone throughout in case of any problems. During the initial one-hour visit, they installed, checked and demonstrated the equipment which included a computer with touch screen and the wired sensors placed in the attachment garments and connected to the XBus. A hard-copy reference manual was left with each participant and they were also given a paper diary to record difficulties when using the system, and any other comments, or alternatively they could use the electronic diary function within the decision support interface. During the second visit, a video recording was taken of each participant undertaking and playing back one exercise session, and users were invited to any raise any questions. On the third home visit, the equipment was removed, and on the fourth visit, each user was interviewed with their carer about their experiences. Users were advised to make their own decisions regarding frequency of usage, with all being aware of the need for exercise repetition to promote upper limb recovery. The experiences and recommendations out of the testing are summarised below.

4.1. *Accommodating the equipment in the home*

Both Mr Jones and Mr Brown lived in sufficiently large houses to be able to leave the equipment out for the entire 2 weeks. Mrs Andrews placed the equipment on a small table in the bay window of her living room. She noted that she and her husband would do '*whatever we need to do to get me as near normal as possible … if something is going to help then it isn't a hindrance'.*

Table 2. Details of volunteers who tested the first integrated prototype.

Name	Age	Year of stroke	Level of functionality/independence	Computer familiarity
Mr Jones	73	2003	Walks independently outdoors with a stick. Has good range of upper limb movement. Independent in all activities of daily living, including driving	Some experience
Mr Brown	68	2006	Walks with assistance from one person. Movement of upper limb restricted with mild left-sided neglect. Help required with most activities of daily living	Some experience
Mrs Andrews	66	2003	Walks with assistance of frame when outside the home. Movement of upper limb restricted. Help required to dress	Some experience
Mrs Watson	37	2005	Walks independently. Has good range of movement. Independent in all activities of daily living	Novice

Mrs Watson lived in a smaller house with her three children. The equipment was placed on a moveable trolley, which was reportedly acceptable in the living room and there were no problems with lost or damaged items. It was unplugged once, but there were no difficulties with re-plugging.

4.2. *Sensor attachments*

Three of the four users experienced difficulty placing the attachment garments in the correct positions on their impaired arm. Reported reasons included lack of control of the limb, which meant that it could not be guided easily into the garment and problems with memory and sequencing; e.g. Mr Brown initially positioned the arm band upside down. Mrs Andrews managed to put on the garments once without help but the resultant effort meant that she achieved fewer exercises due to fatigue. Only Mrs Watson found putting on the garments easy to accomplish without help.

4.3. *Using computer/keyboard/touch screen/diary*

Even though Mr Jones and Mr Brown were both computer users, they emphasised the need for simplicity and were nervous of doing something that might cause a problem. As Mrs Jones (spouse carer) explained, '*It's easy to wipe programmes or something if you just happen to touch something or a wrong button so we just did what we were shown. We did not explore all round*'. Mr Brown was also aware of caution. '*For newcomers to computers and* [*older users*] *like me there is a fear factor*'.

Consequently, neither Mr Jones nor Mr Brown used the computerised diary function to record any notes. In contrast, Mrs Andrews and Mrs Watson found the on-line diary easy to use. Mrs Andrews elected to use the keyboard/mouse rather than touch screen to operate the system because her short stature meant she needed to lean forward to touch the screen.

4.4. *Understanding and using the screen display*

All users experienced some challenges distinguishing between the different buttons on screen and their respective functionality. Mr Jones thought that the screen was '*too busy with buttons*'. He only used the 'play', 'stop', 'repeat' and 'axis' buttons and '*wondered what the other buttons were for; if they were necessary*'.

Video recordings of usage in the home showed that Mr Jones and Mr Brown were both unsure of when to commence the exercise. Mr Brown suggested the inclusion of a series of bleeps so that the user could move in time with the target.

4.5. *Interpreting screen presentations*

All four users adopted different methods to interpret their movements on screen. Mr Jones used the exercise history icon to make detailed comparisons between his movement and the target movement. However, Mr Brown and Mrs Watson both experienced difficulty identifying this icon; so they did not use it. Mr Jones also used the different observational angles to identify differences between the target and his own movement. Mrs Andrews and Mrs Brown both found the ghost mode display more helpful than the split screen in assisting with movement comparison.

As Mrs Andrews explained,

> When you look at the first view it almost looks the same – and I think I'm not far off. But when you look at the front picture it's quite marked – the bending of the lower arm. The picture from above very clearly shows this rotation inwards.' You do things that you don't realise until you see it and then you realise you're doing it wrong.

All users made suggestions for improvements to the screen presentation, and even though ideas varied they all wished to receive useful feedback about progress. Mr Jones suggested that there should be a grid on the display screen to aid comparison. Mr Brown thought that synchronisation of patient movement with the manikin would be valuable. He also suggested the inclusion of a scoring method to show if overall progress is positive despite daily variance. Mrs Andrews wanted to be able to check her progress over each set of repetitions. She was aware that her first two or three movements were better than the latter ones because she tired easily. Mrs Watson wanted a counting mechanism that would tell her how many repetitions she had done as she was doing them. She considered that a score for certain aspects of a movement would make her more determined to improve and thought it would be good to have verbal cues as this would be like being with a physiotherapist. Mr Jones and Mr Brown both said that they would have liked the movement display to be in real time rather than have to wait to upload the information and then play it back.

There was general agreement that the on-screen graphs were not easy to understand.

4.6. *Need for teaching and education*

Mr Brown recognised the need for further explanation over the period of familiarisation;

> After a few days of using the equipment when you learn how to use it and set it up – after a few days you need a physio to ask what you have learnt and to show you other things about the movement and to give you a pep talk and explain how you could use it better.

5. Therapy consultation

Stroke physiotherapists were consulted in December 2006 and February 2007 regarding how they might use the system in practice. In addition to a demonstration, they were shown a video of one of the home-based tests. The views obtained from home-based user testing and therapy consultations (which included views of both utlility and usability) are summarised in Table 3 and were taken forward in the development of the second integrated prototype.

6. The second integrated prototype

From 2006 onwards, the partnership with Philips R&D enabled the use of matchbox-sized wireless sensors, removing the need for a wired system but necessitating a separate charger for the sensors (Willmann *et al*. 2007). Additionally, further movement analyses confirmed the need for a third sensor to capture the movement of the trunk during upper limb motion and the posture of the patient as recommended by the therapists during consultations. A vest style garment was produced to position the third sensor on the body as shown in Figure 5. Other changes from the first prototype included a laptop computer rather than a separate screen and keyboard and optional audio instructions.

Seven separate upper limb movements, identified by expert therapists as being important, were added to the library of interventions. Some of the displays on the decision support interface were changed to reflect user preferences, for example graphical feedback to show the details of individual repetitions as well as average over time.

Before the new prototype was introduced into home settings, the four volunteers who had participated in the home-based testing of the first integrated prototype were invited individually to the university to be video-recorded while testing the new equipment. The outcomes of these consultations informed further refinements to the system prior to home-based testing.

Table 3. Summary of results of user and therapy consultation on first integrated prototype.

Aspect of the system	Purpose of consultation	Issues to resolve (user views)	Issues to resolve (therapist views)
Sensor attachments	Clinical utility and usability	(1) Make clear which way up the arm band has to be worn (2) Consider a more rigid arm band to facilitate independent use (3) Enlarge wrist band and ease of rethreading buckle once opened	(1) Incorporation of three sensors (wrist, arm and trunk) (2) Develop clothing for trunk sensor attachment
Wired sensors	Usability	Remove the need for sensors to have wired connection	
Screen display	Clinical utility and usability	(1) Ensure icons are well differentiated and understood (2) Consider a grid to aid comparison of movement with the ideal (3) Provide a prompt to start the exercise once the "Sensors Ready" screen appears (4) Real time display	(1) Consider the use of prompts to assist user to synchronise movement with target (2) Develop a library of upper limb movements to select from (3) Real time display
Progress charts	Usability	(1) Display average time taken per exercise (2) Develop a score of consistency between patient movements and target (3) Develop a score comparing current patient movement with previous movement (4) Consider tabular presentation	(1) Display speed of movement, range of movement, number of repetitions and a way of showing rotation (2) Develop a score of consistency between patient movements and target (3) Introduce a score comparing current patient movement with their previous movement (4) Introduce a score to identify the quality of movement and where the focus for improvement should be
Text user manual	Usability	(1) Summarise the recording and playback tasks on one page (2) Give clear instructions about the order of putting on attachments (3) Give advice in the event of a system crash – i.e. turn off at PC	
Education	Usability	Consider the need for follow-up teaching once user has gained initial familiarity	Consider the need for therapy education about how to use the equipment

7. Home-based testing of the wireless prototype

A further four volunteers with stroke were recruited to test the second prototype in their own homes, as summarised in Table 1 and described in Table 4. All were male, living with their wives. They had all experienced right-sided strokes, resulting in left hemiparesis. The same methods were used as before to introduce the equipment to volunteers, maintain their involvement and monitor progress.

7.1. *Accommodating the equipment in the home*

These users experienced more challenges accommodating the equipment in their homes than the first group. The equipment was kept on a trolley in a corner of Mrs and Mrs Chandler's dining room but they commented that they would have had to move it for visitors. Mr Cooper used the

Figure 5. Second integrated (wireless) prototype.

system sitting in his usual armchair with the laptop on a coffee table and put it away after use, leaving the sensors and garments plugged in and in the corner of the living room floor. His wife said she did not think any one would want to put all the equipment away every day. Mr Tennant kept the equipment out on the living room table where it was considered to be a nuisance, using space usually reserved for other frequently needed items. His wife said that she could not imagine putting it away again and bringing it out every time her husband wanted to use it. Mr Leeming kept the equipment on the living room table but it had to be moved upstairs when the family visited. His wife commented that if she had to unpack the equipment from the bag each time, they would not have used it at all.

7.2. *Sensor attachment*

The challenges the first group of users reported donning the wrist and arm band and ensuring accurate placement of the sensors were also reported by the second cohort. Additionally, these volunteers also had to manage the vest garment for the additional chest sensor, which they all found problematic due to the attachments and poor fit. None would have managed without assistance. Mrs Cooper noted that the poor fit may have led to inaccurate representation on the screen.

Table 4. Details of volunteers who tested the second integrated prototype.

Name	Age	Year of stroke	Level of independence	Computer familiarity
Mr Chandler	74	2000	Independent with stick Help required with washing/dressing due to limited arm movement	Education and experience
Mr Cooper	68	1996	Independent – some residual weakness in left arm	Education and experience – own laptop
Mr Tennant	80	2001	Used wheelchair both in and out of house. Required help with most ADL activities	No experience
Mr Leeming	59	2001	Able to walk unaided but arm movement very restricted	Experience through running own business

Mr Chandler and Mr Tennant both donned the arm sensors on upside down, leading to contorted images on screen, as experienced by one of the first group of users. Also, the sensor fell out of the pocket of the vest when charging the sensors which led to concerns regarding correct placement for two of the users.

7.3. *Charging system*

Two users forgot that the sensors needed to be charged while not in use and consequently the sensors were unable to communicate with the laptop. Mr Cooper noted that there was not a firm physical connection between the sensors and the charging units which resulted in incomplete charging.

7.4. *Using laptop and interface*

All appreciated the audio instructions. However, as with the previous testers, there was caution about exploring different functions. None of the users made use of the on-screen diary and although there was now a library of movements to choose from, they did not explore the range of exercise tasks, preferring to work with only one or two options. Cursor control proved difficult as it was too small to identify easily, making navigation cumbersome. All users had problems with using the mousepad finding it too sensitive so that it moved on to the next screen before they were ready.

7.5. *Interpreting screen presentation*

Mr Cooper was able to compare his movement with the target movement in the real time display and was encouraged by his progress. He remarked, '*I could tell that I was getting better – it was exactly in line with the [target] line on the screen with the ideal version*'. The other three users were not able to achieve as much movement as Mr Cooper and there was therefore a bigger difference between the target movement and their own. This led to Mr Leeming feeling that he was not able to make good use of the system. Occasional inaccurate sensor placement by Mr Tennant and Mr Chandler led to the screen presentation being difficult to interpret and understand. Mr Tennant's wife explained that because the movements looked wrong on the screen, he was soon discouraged from using it. She said, '*Since his stroke he has been quite black and white. So if things are not right – it throws him*'.

The bar chart giving the time taken to carry out the movement was easily comprehended, but none of the users found the graphical display of the range of movement easy to understand as it was not clear to them what was being measured. Mrs Cooper suggested that the system might be programmed to give audio and/or text feedback if the user had done well with a particular movement or alternatively suggest that a movement might be repeated if it was not conducted correctly.

7.6. *Robustness*

There were difficulties with system robustness due to both user and equipment error. The introduction of the sensor charging units led to two users incorrectly using the system with the sensors still plugged in, resulting in error messages. Mr Chandler and Mr Tennant also experienced the system not recognising the sensors due to sensor degradation even though they had correctly carried out the on-screen instruction. Mr Tennant also found that for a week of using the system, it did not record any of the movements. It was unclear whether this was due to a system fault or due to incorrect undertaking of instructions.

7.7. *Overall use of system*

All four users did not use the system as often as the previous testers. Only Mr Cooper used the system most days. Mr Cooper considered that it would have been daunting if he had been asked to use it soon after his stroke. However, he felt that it was a confidence booster as he could identify improvements. He said

> Once you realise you are getting better it builds your confidence. Since I have been using the system the movement in my arm is much better. I am more confident about using my left hand … I feel a bit more as if I want to use it.

The other users were less motivated to use the system because they had more restricted arm movement and felt that the demands of system were too advanced for them. Both Mr Cooper and Mr Leeming underlined the importance of the system being used alongside a physiotherapist. Mr Leeming said, '*If I had to rely on this machine rather than see a physiotherapist I wouldn't be very hopeful at all at making any progress*'. Mrs Chandler, however, noted the value the system offered by saying '*you could use it as often as you want … could use it a number of times a day rather than wait for the physio to come and give them an hour*'.

7.8. *Summary of second round of user testing*

The results demonstrate that even though some usability issues had been resolved in the second prototype, others had emerged. Also some of the problems which had emerged out of the first round of testing had not been fully addressed and had again been raised by the second group of testers. Additionally, as this second group contained only one expert user already familiar with the research programme, there was possibly reduced confidence in and commitment to participation, expressed through reduced willingness to tolerate the equipment within the home.

8. Discussion

This project demonstrates the imperative for end-user engagement at all stages of the research process and raises important issues both for this research programme and for other research into telerehabilitation. The involvement of clinical researchers alongside technologists ensured that the complex mix of physical, communication and cognitive impairments which typify stroke were fully taken into account in the development of a system that is intended to be both simple to use and to interpret and will also meet the goals of clinical practice. However, the demand for high levels of clinical utility which are necessary for the delivery of rehabilitation through technology can also compromise usability. Consultations with physiotherapists led to requests for improvements. There was unanimous agreement that a third sensor was necessary to provide data on trunk movement which is then required to be securely and accurately attached to the upper chest for successful movement replication. The usability tests of the second prototype confirmed the inappropriateness of the vest solution from both clinical utility and usability perspectives, with the design warranting full reconsideration. Thus, while greatly improving the potential of the system from a clinical perspective, the usability still poses a significant challenge.

As the aim was to create a simple and accessible system, the introduction of wireless sensors was perceived to be a significant advance towards achieving this and will undoubtedly be a requirement for any system that might be mainstreamed in the future. However, the results obtained from testing the second prototype suggest that technological improvements do not necessarily equate with overall improvements in usability. The introduction of wireless sensors greatly simplified some aspects of system usability, but they also resulted in other demands upon the end-user and their carer due to the necessity for regular charging.

These and other examples illustrated during the testing conducted to date demonstrate the important overlaps between technology, clinical utility and usability, and the 'trade off' that is sometimes necessary between these different elements for success. Any one aspect of the system cannot be effective without concurrent consideration being given to the other two.

The research challenge is to arrive at an optimal balance between level of technological sophistication, requirements for clinical utility and device usability, taking into account the varying perspectives and requirements of end-users, carers and professionals.

Research is on-going to further refine the prototype with a focus upon user comprehension of the screen display and motivation to use the equipment.

9. Recommendations

Several key recommendations can be identified from the results of consultation.

Firstly, the outcomes achieved to date can be attributed to high degree of interdisciplinary working which spanned engineering, informatics, medical physics, ergonomics and psychology, design and therapy researchers. This proved essential for the undertaking of this ambitious research programme which has centralised the involvement of end-users.

Secondly, the experience of user testing underscores the highly individual requirements of individuals and the resultant need for flexibility from the system. It is essential that there is the capacity to accommodate specific individual needs. These include (but are not limited to) different learning styles, extent of previous exposure to technology, the varying physical size of individuals and the consequences of stroke-induced impairments. Additionally, to be accepted and used on a regular basis, the equipment has to be successfully incorporated into the user's living accommodation and daily routines as well as those of the people they live with. Therefore, it needs to be aesthetically acceptable, robust, simple to use and easily stored. Attention must be given towards ensuring safe use in the home environment.

Thirdly, the testing confirmed that professional support must be available before and for the duration of device use. Otherwise, users easily become anxious and lose confidence. The results of testing also highlight the adverse effects of system breakdown. Therefore, there will be a need for a whole service infrastructure to support the introduction of these forms of home-based technology.

The final recommendation supports the previous point. This paper has focused upon describing end-user experiences. Usage by professional staff also resulted in a list of considerations which spanned clinical utility and usability which need to be taken into account during device development and testing, and in the development of the necessary service infrastructure.

10. Conclusions

One of the goals of current government policy is to promote use of technology by older people and those with long-term conditions, with envisaged applications including those for support and enablement, self management and rehabilitation. There is little doubt that telerehabilitation will be adopted in the future. The research undertaken by the SMART Consortium illustrates the complexity underpinning system development and the essential and substantial involvement of end-users in the entire research programme.

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