# Virtual reality, haptics and post-stroke rehabilitation in practical therapy

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## ABSTRACT

We address the question of *usefulness* of virtual reality based rehabilitation equipment in practical therapy, by letting experienced therapists explore one such equipment during six months in their regular practice under natural circumstances. By protocols, questionnaires and focus group interviews we collect data regarding which activities they considered useful, why these are useful and what might improve usefulness of such activities, based on the therapists' professional judgement and experiences. This resulted in a set of purposeful activities, identified values for therapeutic work, and design guidelines. The conclusion is that such equipment has benefits beyond real life training, that variation in content and difficulty levels is a key quality for wide suitability and that the combination of challenging cognitive activities which encourage motor training was considered particularly useful.

## 1. INTRODUCTION

Stroke is the number one cause of adult disability and the third leading cause of death in the US (American Stroke Foundation, 2008). Globally, 15 million individuals per year get stroke (Internet Stroke Center, 2008). Moreover, stroke is a devastating condition that often results in serious long-term complications. Rehabilitation is mostly necessary and of long duration and even though clinical rehabilitation works well, home based or out-patient rehabilitation works less successful (Broeren et al, 2008). In this work, we therefore focus on out-patient rehabilitation in practical therapy, where most long-term rehabilitation work takes place.

Stroke can cause a wide range of cognitive as well as motor impairments. Cognitive impairments can affect comprehension, memory, visual recognition, attention, and task sequencing (Connor et al, 2002), as well as motor impairment such as reduced upper limb mobility, paralysis on one side or impairment in balance. Every stroke is different; therefore every stroke survivor is different (American Stroke Foundation, 2008), but most suffer from both cognitive and motor impairment. By providing training for both simultaneously, virtual reality (VR) can enhance stroke rehabilitation (Broeren et al, 2006; Broeren 2007; Goude et al 2007; Katz 2005; Kizony et al, 2004; Hilton et al, 2000; Hilton et al, 2002). Motor training can be provided by haptic force feedback interaction devices and cognitive training by tasks in the virtual environment.

In this study we address the question of *usefulness* of such VR-based rehabilitation equipment in practical therapy, raised by (Edmans et al, 2004) as the most important question. Our aim is not to determine whether particular equipment is useful or not, rather do an open-minded exploration of different aspects of usefulness perceived by experienced therapists in a natural usage situation. From their experiences, we then do an in depth analysis of *which activities are considered useful*, *why they are useful* and what might *improve*


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*usefulness of such activities*. As the relationship between motor and cognitive abilities is complex and interrelated (Kizony et al, 2004), we do not a priori look for example activities particular for training motor functions (as in Henderson et al., 2007; Sugarman et al, 2008), but take a holistic, "bottom-up" approach to usefulness including all aspects.

Hence, our results will primarily be based on the therapists' experiences and professional judgement of using the equipment. It has been claimed by Martin et al. (2006) that in particular developers of medical devices ought to incorporate user requirements into their development processes, since poor usability increases the risks associated with medical device usage. To understand usage, the often complex interplay between users (i.e., staff and patients), the medical equipment, the work task and the use environment need to be considered. It is within this context that the use qualities of the technology emerge and, consequently, where the requirements for the technology are defined (Karlsson et al, 2007). Shah and Robinson (2007) have identified benefits of user involvement which includes discovery of conceptual deficiencies and potential problems in current and future equipment; and to propose changes and solutions to these problems (Garmer et al. 2004). Furthermore, user involvement helps elicit user needs, opinions, expectations, and experiences that may prove critical to the deployment of a technical product (Luck, R. 2003)

The rationale behind occupational therapy is to promote recovery through purposeful activity (Edmans et al, 2004). In order to approach the complex notion of usefulness, we have taken the perspective of the therapists' interest, and therefore decomposed our research question in the following sub-questions:

*i)* What types of activities are considered purposeful (by practitioners and patients)?
*ii)* What value can such equipment have for therapeutic work (according to practitioners)?
*iii)* What usability issues are of particular concern for users with cognitive and/or motor deficits?

The purpose is to better understand practical issues regarding usefulness and usability of VR-enhanced stroke rehabilitation. The long-term goal is to develop a design theory for VR-enhanced stroke rehabilitation, including a classification relating activities with deficits to rehabilitate. Such theory can be used to design more useful rehabilitation support and to guide the design of further studies of rehabilitation effects.

## 2. RESEARCH APPROACH

This work is based on collaboration between researchers and developers of VR-based equipment for stroke rehabilitation, researchers of interaction design interaction technology usage, researchers as well as practitioners in physical and occupational therapy.

Our overall methodology is a user-centred approach to design (Dix et al, 1998; Preece et al, 2002), in a realistic setting (Beyer and Holzblatt, 1998), since practical usability issues require realistic settings (Wattenberg, 2004). A user-centred, iterative approach to design which involves users is crucial when designing for disabled (Dickinson et al , 2002; Dickinson et al, 2003; Wattenberg , 2004). For this research, we use an iterative model to collect experience from clinical practice, increase our understanding of usefulness and usability, develop the equipment accordingly, and re-evaluate in clinical practice.

To approach our research question, we have studied usage of a VR-based rehabilitation equipment under development during practical therapy. The study has the following characteristics: a non-specialist environment, a natural setting and usage over time. The reason we have chosen a non-specialist practice is threefold: (1) Previous studies of the equipment focused on laboratory or stroke-specialist settings (Broeren et al, 2006; Broeren 2007). (2) Most long-term treatment takes place in non-specialist organizations, and therefore the equipment must be usable in such organizations without specialist competence. And (3) general purpose therapists treat a wide range of patients which may allow for a broader perspective on value and usefulness. Even though stroke rehabilitation is the main purpose of the equipment, other patient groups may benefit from the same type of training. Therefore, the broader experience of these therapists may be valuable.

By a natural setting, we mean a setting which is as close to introductions of new equipment as possible. The therapists got a short introduction to the equipment, and were provided with available instruction material. There were no developers or researchers present during the use period, except as for contacts when technical support were needed. They were asked to use the equipment as they found appropriate, as one among other rehabilitation tools. It was used over an extended period of time, so that usage over time could be followed for various patients, which is important for evaluating for instance motivational effects of the new equipment.

## 3. THE EQUIPMENT

The studied equipment is a virtual reality workbench with a haptic, force feedback interaction device (Goude et al, 2007; Broeren et al, 2006), recently being commercialized (www.curictus.com). The environment provides a wide range of activities through a library of casual 3D games (casual game n.d., 2008). At present there are 15 games available, including Memory, Bingo, Space tennis, Master Mind, mimicking sound sequences and various games involving throwing balls and arrows to different targets. The games are steered with the haptic input device, which is a pen positioned under the glass surface in the middle (see fig 1) where the 3D picture is projected. The pen also gives haptic feedback such as feeling the force from throwing a ball or touching a surface.

The level of difficulty can be varied in most games, and there is an award system (points) judging the user's performance playing the game. There is also an assessment test – a point test (two left pictures in figure 2), judging the user's performance regarding trajectory path, precision, accuracy and velocity.

**Figure 1.** *The work bench.*

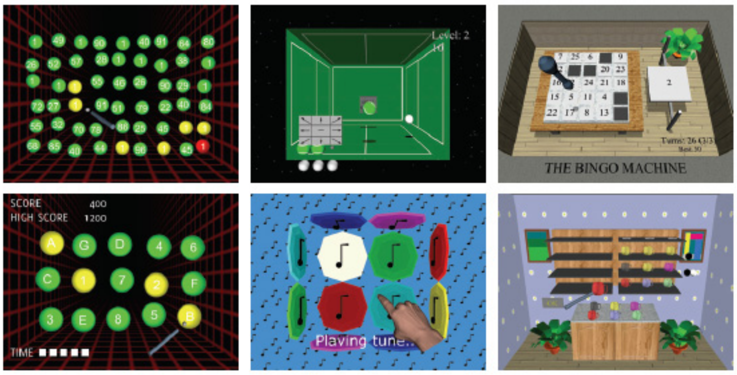


**Figure 1.** *Examples from game library menus.*
*Top row: Assessment test, Space Tennis, Bingo*
*Bottom row: easier assessment test, Sound Sequence, Master Mind*

Due to the variety offered, a game library is more appropriate for our exploration of purposeful activities than tailored activities such as coffee making (Hilton et al, 2002; Hilton et al, 2000) or street-crossing (Katz et al, 2005). Motivation is a success factor for rehabilitation (Edmans et al, 2004), and games are good for motivational purposes (Goude et al, 2007; Pareto 2007). Since motivation tends to decline by time, the variation of activities and the engagement game-playing yields are important aspects for long-term treatment.

## 4. THE STUDY

The study was performed in a small, general rehabilitation centre, deploying therapy for out-living patients. It lasted for 6 months and involved 2 physiotherapists and 1 occupational therapist. They participated by their own choice, because of interest in testing and evaluating this new rehabilitation equipment. They all had long professional experience in their respective profession, and were used to work together as a team. No one had prior experience with computer based rehabilitation support. During this period, they were provided with one prototype VR-based work bench of the type described above, which was placed in a room in the centre.

Since our aim was to find out as many different aspects of usefulness and usability issues as possible, we didn't want to restrict the use in any way. Therefore, we only showed the equipment to the therapists (how it was handled, which games it contained and how the assessment test was used), and then we let them try it out on their own for a while (see figure 3 below). They were provided with the user manual explaining basic information of how to operate the equipment, and short instructions to each game. They received no information of how the equipment previously had been used for rehabilitation purposes, neither any directions of what the different games could be used for. The only direction they got was to use it as they found appropriate. This was on purpose, since we wanted their evaluation to be truly explorative.

### *4.1 The Evaluation Procedure*

The concrete evaluation procedure was designed in collaboration between the developer, the interaction design researcher and the involved therapists in a few meetings. The different parties' interests, available resources and time limitations were negotiated and resulted in the following procedure:

**Figure 2.** *One therapist testing the equipment.*

During the evaluation period, each therapist should offer the new training equipment to those of their regular patients as they judged the training appropriate for, not restricted to stroke patients. Thus, subject inclusion criteria were based on the therapists' judgement and knowledge of their patients solely, as common when introducing new equipment for rehabilitation training. The therapists designed an individual training program using the equipment for each subject, including personal status of abilities, purpose and goal of training, frequency and length of sessions and planned training period. Each subject was to take the assessment test regularly. Two protocols were developed, one for the individual training program, and one for each session to be filled out by the responsible therapists after the session. The latter included information on which games the subject choose to play, information about their performance (both measurements of assessment tests and subjective judgements by the therapist), problems with the games and the equipment and experiences of the usage during the session. The developer gave technical support when needed, on distance.

Each patient was interviewed by their therapist after the entire training period, regarding their experiences using the equipment. The therapists' and their patients' experiences as well as their professional judgements were collected in focus group interviews by the researcher in the middle and at the end of the evaluation period. Focus group interview is a suitable method for use elicitation (Garmer et al., 2004). The focus was on their different usages, patients' reactions and experiences, what was considered useful, what different features they used, problems and benefits with the equipment. The interviews lasted for half a day, and were recorded. The protocols were collected and analysed by the researcher, and the results were summarized, discussed and interpreted together with the therapists during the final interview. The therapists also summarized their use experiences for each game in a document, were they had identified valuable aspects of the games, problems and also gave suggestions of alterations and extension they would like to have.

Finally all collected data was synthesized into a set of activities identified as purposeful, a set of values identified for therapeutic work, and a set of design guidelines derived from the usability issues discovered during the evaluation period.

### *4.2 The Subjects*

During the evaluation period, 15 regular patients were judged to be suitable for the training in question, and were therefore offered this new training method. They all tried the equipment, but three patients chose to stay with their current training methods. The remaining 12 subjects used the equipment according to their individual plan. Most subjects used the equipment for 1-2 hour sessions twice a week. Their respective training periods ranged from 3 to 12 weeks, depending on the remaining evaluation period and how long they wanted to proceed (for instance, one subject quit early due to family reasons). The age range varied from 20 to 85 years old, and was rather evenly distributed within that range. Four subjects were women and eight were men. Four subjects had other reasons for their disability than stroke. The non-stroke subjects suffered from fractures affecting upper limb mobility (2 subjects), burn injury or multiple sclerosis.

### *4.3 Next Design Iteration Cycle*

The result from the evaluation has been used in the next cycle of the iterative design, in the continuing process of development the equipment. The developers wanted to extend the game library with new games dedicated to training stroke patients with neglect which is recognized as a deficit suitable to address by virtual reality (Kizony, 2004; Katz et al, 2005). For this purpose the design guidelines were used and refined.

Two new games were designed, which are currently being integrated in the game library. Also, an interactive instruction video explaining usage was developed.

## 5. RESULTS

The study resulted in the following findings corresponding to the questions raised:

*i)* identification of purposeful activities in two categories: motor or cognitive training;

*ii)* identification of values for therapeutic work; and

*iii)* design guidelines particular for stroke rehabilitation equipment.

### *5.1 Purposeful Activities*

The activities identified by the therapists are organized according to their main purpose. Purposeful activities for motor training include precision, speed and path directness in target finding; variation in hand angle or arm movements; speed control, strength control and rhythm; and combinations of the above. Tasks requiring both precision in direction and variation in strength were mentioned as one such useful combination. Also, the "repeat sound sequence" game was good since the sound buttons were located around all walls in the virtual room, so the user needed to twist the hand in different angles to reach them.

Purposeful cognitive training found in the games include hand-eye coordination; short concentration tasks; attention training; visual search; anticipation; depth perception; strategic planning and problem solving; and different combinations of these. In particular the hand-eye coordination was mentioned often as meaningful, since the user couldn't see their hand and had to sense the placement relative to the virtual room. The combination of strategic planning, reasoning and problem solving found in Master Mind was considered good training. Short concentration tasks such as remembering a played sound sequence, and games that required visual search all over the screen were considered to be purposeful training for many patients.

### *5.2 Values for Therapeutic Work*

The values identified were mainly of two kinds: support to engage and motivate the patient and support for assessment. The variation of exercises and the engagement the game playing reached were appreciated, particularly for cognitive training. For assessment purposes, the objectivity in diagnostic tests, the support to judge cognitive abilities, and the support for performance and progress analysis were considered both new and valuable.

The equipment was considered useful for both cognitive and motor training, but the cognitive aspects were mentioned more often, in particular as a motivational driver for motor training. When asked about what was most important for playing the games, the cognitive or the motor ability, the therapists considered the cognitive aspect much more important for performance:

> *"If you have problem interpreting what to do, it does not matter how well you can steer the pen. The motor ability can be compensated by twisting the body or using the shoulder – if you know where to go."*

Also a patient stressed the cognitive aspect as important:

> *"I get to train motor functions and move the pen, and to all the time be alert and concentrate on what I'm doing, it does not work if I lose concentration no matter which game I play. The more I play the games, the more I think I improve all the time."*

### *5.3 Design guidelines particular for stroke rehabilitation equipment.*

The design guidelines address the following areas: variability in content; difficulty level and speed; consistent behavioural simplifications of real world objects; ability levelled interaction schemas; multimodal feedback; performance and progress feedback; user appropriate instructions. In particular for long-term usage, the variation in content becomes crucial. The variability in difficult levels is one of the most important aspects, and can be applied to various parameters such as content (e.g., similarity in pictures in Memory), contrast (e.g., distinct back- and foreground or a diffuse naturalistic milieu), or required precision for targets.

These guidelines extend or are in accordance with the guidelines in (Hilton et al, 2000; Lövquist and Dreifaldt, 2006), except for the aspect of realism. Our study suggests that realism is not required, as long as behavioural simplifications are reasonable relative to real world experience. This can probably be explained by the difference in content: here a game environment is used, not a simulation of real world activities.

## 6. DISCUSSION & FUTURE WORK

The long-term ambition with the work bench is to make it suitable for patients' home-based training. For reaching this goal, a user-centred, iterative design process is crucial, and needs to be continued:

> *"Many patients needed a lot of supervision, we had to be with them all the time, so the equipment is not yet user-friendly enough – not for unsupervised home-based training."*

The practical evaluation in such early stage of development was much appreciated by the therapists:

> *"It is positive when someone is happy for all the errors we found, that's very unusual. But it was the purpose of this project – to make it [the equipment] user friendly before reaching the market. Often we receive new equipment and there are lots of things which are not good and we need to tell them [the developers], only resulting in a sigh: the product is finished."*

Our study design with a natural setting, long-term usage and explorative approach had several benefits. The natural setting with no third party present during usage, we believe was important for evaluating real usability issues: the presence of an equipment "expert" will consciously or unconsciously guide the users into pre-determined usage and thereby not discover other ways of acting with the tool. To study usage over time is important for evaluating attractiveness of activities and motivational effects. A one-time usage of 30 min (as for instance in Lövquist and Dreifaldt, 2006) can say very little about this quality.

The explorative setting with full user responsibility showed good potential for helping development progress. The users gave many valuable suggestions for improvement, as often is the case (Garmer et al. 2004), among those were:

> *"I would like to have a game which even more [than the sound sequence game] made the user twist her wrist and force using the hand in many different positions such as carve a bowl for instance."*
>
> *"I would love to have an assessment tool helping to judge suitability for keeping the driving license – we see patients who really shouldn't be driving a car, but since this is such an emotionally difficult restriction – it is hard to say something without a good ground for it."*

Finally, focus groups worked well for discussing different usages and viewpoints, as claimed by (Garmer et al, 2004), and generated many interesting discussions:

> "*We have seen different things, the three of us"*

### *6.1 Future work*

Our long-term goal is to develop a design theory for VR-enhanced stroke rehabilitation. Here, we have studied perceived usefulness (Hassenzahl and Sandweg, 2004; Davies, 1989) and anticipated effectiveness with the purpose of informing future development of the technology. However, other types of studies are needed to confirm actual effectiveness. Also, actual usefulness must include consequences for real life transfer, which is increased ability due to rehabilitation efforts. This is a challenge to show, well illustrated by one patient's response to the question of improvements:

> *"It is difficult to say what exactly is the cause of a recovered ability, abilities just re-appear from time to time without any apparent reason."* (patient, 9 years after stroke).

## 7. CONCLUSIONS

Virtual reality with haptic force feedback has benefits beyond real life training:

> *"It is a good point that they can't see it [the hand], they cannot compensate the deep sensation of their hand by vision, they have to feel it. They may think the hand is positioned somewhere in the picture [virtual room], but the pen shows up elsewhere – oops".*
>
> *"One patient was extremely afraid of using her hand, but in front of the computer she completely forgot to be afraid".* (About patient with broken wrist)

Games as activity base are motivational beyond real life training:

> *"The scoring of the games is motivating – I could never get them to move around other [physical] things or play a [physical] move-around game for 45 minutes, as they did with the computer. One I had to throw out after 1 and ½ hour because I had to go home – they would never sit for 45 minutes so intensively!"*

*"I think this is good actually, I have tried this during the summer about 15 times I think. In the end of each session I get a test, and then I should push the green dots as fast as possible… the time is measured and sometimes I do well and sometimes not so well. I'm trying to get below 30 seconds, I'm currently at 31,4…"* (patient)

Variation of activities and levels is vital for attractiveness and wide suitability, due to patients varying abilities and taste: different patients liked and were capable of using different games at different levels:

*"Space tennis was absolutely most popular. Memory was chosen by many also, and surprisingly had some difficulties that I didn't expect: Remember the positions, there are after all only 12, still they had problems finding the pictures. Bingo was also rather popular."*

*"The ones, who liked Spherix, have not been neurologically impaired, but they needed wrist mobility and coordination training. Suitable for motor impairment, if their cognitive ability is reduced they do not manage this game."*

Particular the combination of challenging cognitive activitiess which encouraged motor training was considered useful:

*"For cognitive and motor training of arms and hands, there is a market [for this equipment]. It gives possibilities to assess cognitive ability which we haven't had before."*

*"I will miss it. If we had it in the organisation, I could use it when I needed, that would have been great!"*

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