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User-centered design of a patient's work station for haptic robot-based telerehabilitation after stroke

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Abstract: Robotic therapy devices have been an important part of clinical neurological rehabilitation for several years. Until now such devices are only available for patients receiving therapy inside rehabilitation hospitals. Since patients should continue rehabilitation training after hospital discharge at home, intelligent robotic rehab devices could help to achieve this goal. This paper presents therapeutic requirements and early phases of the user-centered design process of the patient's work station as part of a novel robot-based system for motor telerehabilitation.

Keywords: rehabilitation robotics; stroke rehabilitation; telerehabilitation; user-centered design.

1 Introduction

Stroke is one of the dominant causes of acquired disability [1] and it is the second leading cause of death worldwide [2]. The high incidence of the disease and the current demographic developments are likely to increase the number of stroke patients in the future. Most of the survivors have physical, cognitive and functional limitations and require intensive rehabilitation in order to resume independent everyday life [3]. Therefore, the main goal of motor rehabilitation is relearning of voluntary movement capability, a process which takes at least several months, some improvement can occur even after years. In the rehabilitation clinic, patients usually receive a daily intensive therapy program. However, for further

improvement of motor abilities, severely affected patients are required to continue their rehabilitation training outside the rehabilitation settings, after being discharged from the rehabilitation clinic. Langhammer and Stanghelle [4] found that a lack of follow-up rehabilitation treatment at home leads to deterioration of activities of daily living (ADL) and to motor functions in general. A possible solution is an individualized and motivating telerehabilitation system in the patient's domestic environment. Some studies [5, 6] have confirmed the advantage of home rehabilitation after stroke and showed that telerehabilitation received high acceptance and satisfaction, both from patients, as well as from health professionals [7]. Most of the existing telesystems [7, 8] are based on audio-visual conferencing or on virtual environments and contain rather simple software for monitoring patients' condition. However, in neurological rehabilitation the sensorimotor loop needs to be activated by provision of physiological haptic feedback (touch and proprioception) [3].

Robot-based rehabilitation is currently one of the most prevalent therapeutic approaches. It is often applied in hospitals alongside conventional therapy and is beneficial for motor recovery [9]. Rehabilitation training including a haptic-therapy device may therefore be even more promising for home environments than non-haptic telerehabilitation. Several telerehabilitation systems, which include not only audio and visual, but also haptic modality, already exist [10, 11]. Most of these solutions use low-cost commercial haptic devices (e.g. joysticks) for therapy training, with the goal of cost minimization and providing procurable technology. Nonetheless, devices specifically developed for stroke rehabilitation, which are already established in clinical settings, may have greater impact on motor relearning and could therefore also be more effective at home, compared with existing home rehabilitation devices.

In a previous paper [12], we presented a concept and design overview of a haptic robot-based telerehabilitation system for upper extremities which is currently under development. In the present work, we describe therapeutic requirements, user-centred development [13] and implementation of the patient's station of the telesystem.

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2 Patient's work station

The telerehabilitation system [12] is based on two therapy devices: Reha-Slide for unilateral or bilateral training of up to three degrees of freedom (DOF) of the shoulder, elbow, and flexion or extension of the wrist [14] and Bi-Manu-Track for bimanual training of one DOF, pronation and supination movement of the forearm and flexion and extension of the wrist [15]. Both systems can be used by the patient as an autonomous exercise tool (in autonomous mode) or for one-to-one sessions with a therapist or medical doctor (in telesupervision mode). In telesupervision mode, a therapist communicates with a patient through audio, video and haptic channels and exchanges data and information with the patient in real time. In autonomous mode, the patient trains with a haptic device that is part of the patient's work station at home. On the other side, at the therapist's work station, which is located in a rehabilitation clinic, the therapist can monitor the training and analyse the data that has been logged during training.

The patient's work station is an imperative part of the telerehabilitation system, encompassing a major portion of the patient's user interface. The station should therefore encompass technical solutions for all therapeutic requirements and patients should be able to use the station independently.

2.1 Therapeutic requirements

To define the components of the patient's work station five therapists were interviewed in focus groups. Since they were working in two different rehabilitation clinics, we conducted two focus groups with two and three therapists, respectively.

As a result, we obtained the clinicians' requirements of the station in regard of hardware and functionality. The requirements of the main user interface and the system navigation are described in a previous paper [16]. In the present paper, we summarize hardware and ergonomic aspects of the telesystem.

The following key hardware components of the patient's station were identified:

1. Mouse and keyboard are not suitable for stroke patients as input devices. Operation of the system should be enabled through touch screens or large-size buttons.
2. Visualisation of the tasks, therapeutic games and navigation in the system should be displayed on a computer screen.

3. Web cameras and microphones are necessary for communication with a therapist.
4. Implementation of body posture-recognition is needed for detection of compensatory movements during exercise execution. A motion-capturing camera is therefore required.
5. A therapeutic haptic-device should be used for the rehabilitation training.

3 User study

In order to further specify ergonomic requirements, we carried out a user study. This study was conducted in cooperation with a clinic for neurological rehabilitation and aimed at analysing the requirements of hemiparesis patients' work station. The study aimed at answering the following research questions:

- Which ergonomic requirements must be met in order to allow patients to work as independently and comfortably as possible?
- What technical equipment is necessary for data entry via touch screen?
- How can patients be aided in independent work with both rehabilitation devices (Reha-slide and Bi-Manu track)?

3.1 Method

In this study we used a 10" tablet PC, a 17" standalone touch screen monitor, a Reha-Slide and a simplified Bi-Manu-Track to simulate the patient's workplace. To display input buttons on both touch screens (i.e. on the tablet and on the standalone monitor) we created an interactive slide presentation. This presentation showed a series of interactive buttons that systematically varied with respect to specific characteristics (e.g. size, orientation, position, labelling, contrast). Participants proceeded to the next presentation slide by successfully pressing an automatically selected button on the corresponding screen. To simulate a training session with the Reha-Slide, a simplified exercise was implemented, in which the movement of the Reha-Slide was shown as a line on the touch screen monitor. With regard to both devices, Reha-Slide and Bi-Manu-Track, we were interested in the patients' preparation procedures and in analysing their ability to perform the relevant activities correctly and independently.

Participants were tested in one individual session. They had to solve given tasks, i.e. clicking buttons on one of

Figure 1: Data entry via standalone touch screen monitor (left) and tablet PC (right).

the two touch screens, preparing the training with both devices and conducting a simplified training session with the Reha-Slide (see 3.1). Data was collected by observation and through an open post-session interview. Based on the results, usage problems were analysed qualitatively. To support the analysis, all sessions were also videotaped. Based on the results, requirements for the patient's workplace were defined.

Four men and two women with hemiparesis participated in the study. Their age ranged between 39 and 79 years. Two of the six patients suffered weakness in the right half of their body. The severity of the hemiparesis varied between “severely affected” and “mildly affected”. Performance in activities of daily living ranged between 50 and 100 on the Barthel scale ($M=74.17$, $SD=19.02$). Three patients sat in a wheelchair, the others used a walker. In all sessions, a test instructor, a person who documented the results and two occupational therapists were present.

3.2 Results

It appeared necessary that the table height be adjustable so that a wheelchair can be easily placed under the desk adjacent to the table. A mount for walkers could make it easier for the other patients to sit down and to get up without further assistance.

Compared to the standalone touch screen monitor, which participants rated to be best placed at a distance between 28 cm and 46 cm from the front edge of the table, buttons on the tablet PC could be recognized and pressed more easily and reliably. Since the tablet PC can be positioned on the side of the non-affected half of the body, the use of this second interface provides high flexibility (see Figure 1). The size of the interaction elements and higher contrasts were found to be the most important factors determining readability and input accuracy.

With regard to the preparation of both devices it became obvious that several product innovations will be necessary. All patients showed severe difficulties in fixing

the stroke-affected hand and in laying the forearms in the respective pads (Figure 2). Moreover, during training the fixed hand often detached from the device, causing a change in the positioning of the arms, without the patient being aware of this change. Descriptive results of the study are summarized in Table 1.

4 Implementation of the system

Based on clinical requirements and on results of the user study, the patient's work station with integrated haptic devices has been developed as shown in Figure 3. A metal construction, which integrates all of the station's hardware elements was developed, taking the conclusions from the aforementioned user study into consideration. The therapeutic haptic devices (Reha-Slide and Bi-Manu-Track) were attached to the construction, as well as a camera (Kinect V2), which was selected for movement capturing and controlled by a portable Intel NUC computer. The position of the camera allowed capturing the patient's upper body, hands and arms.

In regard to the screens, the user study has clearly shown that the patient's workplace should comprise two screens: A standalone display for data presentation and a touch screen for data entry, the latter placed in the patient's reach. In the current patient's station version, a Lenovo ThinkPad Yoga was implemented as an input touch screen.

5 Conclusion

In this paper, we presented the patient's work station as one of the main components of a novel haptic telerehabilitation system. For development of the station we applied a user-centered approach [13]. We conducted an interview with therapists and a user study to define the therapeutic and ergonomic requirements on the station. Based on these results, the first version of a patient's work station was developed. The focus of this work was to identify basic ergonomic requirements for the first prototype of the system. In this pre-development stage of the project, the user study followed a qualitative approach and did yet not include quantitative methods (e.g. users' satisfaction questionnaires).

Following the concept of user-centered design [13], further iterative evaluation cycles of the first prototype of the patient's work station are essential to identify additional requirements which may have not been identified in the current analysis. At these further stages, subjective

Figure 2: Self-fixing and self-detaching the stroke-affected hand.

Table 1: Description of the sample and descriptive results of the user study.

Participants	01	02	03	04	05	06
Gender	m	m	m	f	m	f
Age	66	79	61	75	53	39
Severity of hemiparesis	C	D	A	–	D	A
Affected half of the body	L	L	R	L	R	L
Pleasant distance to main screen in cm	28	46	46	35	39	27
Preparation of training with Reha-Slide (on its own)	2	2	1	1	3	1
Preparation of training with Bi-Manu-Track (on its own)	1	1	1	1	1	1

L, left; R, right; 1, only with help; 2, with advice; 3, without help. Severity of hemiparesis varies between “A = severely” and “D = mildly”.

Figure 3: Implementation of the patient’s work station based on Reha-Slide (left) and Bi-Manu-Track (right).

outcome variables, such as perceived utility, acceptance, and intention to use will be measured additionally. The requirement of integrating two screens into the station

raises the question of how the presentation of interaction elements can be combined on both screens in a coordinated and understandable manner. For this purpose, different

interaction concepts will be developed and tested in a following user study.

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