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Requirements for a home-based rehabilitation device for hand and wrist therapy after stroke

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***Abstract*—Recovering hand function to perform activities of daily living (ADL), is a significant step for stroke survivors experiencing paresis in their upper limb. A home-based, robot mediated training approach for the hand allows the patient to continue their training independently after discharge to maximise recovery at the patient's pace. Developing such a hand/wrist training device that is comfortable to wear and easy to use is the objective of this work. Using a user-centred design approach, the first iteration of the design is based on the requirements derived from the users and therapists, leading to a first prototype. The prototype is then compared and evaluated against the required features. This paper highlights the methodology used in the process of validating the design against our initial brief.**

***Index Terms*—Rehabilitation, hand, wrist, requirements, orthosis**

I. Introduction

Motor function deficits in the upper limb are prevalent in 80% of stroke survivors [1]. Normal hand function is expected to perform Activities of Daily Living (ADL), and hence its training alongside the proximal segments helps to improve functional recovery [2].

Most conventional post-stroke rehabilitation takes place in the form of a one to one session in a clinical environment. In conditions like the ongoing pandemic, the patient must be able to continue training without direct contact at their own home. Robot-aided rehabilitation helps to achieve this by allowing the user to train for a longer duration, several times a day, without fatigue caused by travelling to and from the clinic. Thus the user would be able to train at a higher intensity which has shown to improve recovery of arm function [3]. Remote supervision also increases productivity and reduces the pressure on the health care system.

The objective of this research is to design a home-based rehabilitation device for the hand and wrist that facilitates active initiation and execution of movements. In this paper, we discuss the different user requirements of such a device and the methods of evaluation to verify that the prototype iterations meets these requirements.

II. Design Methodology

A cooperative approach involving users at every stage is adopted in the design of this device. Firstly, a review of the state of the art identified several contemporary works that focus on post-stroke training of wrist and fingers such as Gloreha [4], Hand of Hope [5], Saebo Flex [6], and SCRIPT SPO [7]. In engaging with the potential users, the SCRIPT researchers used methods such as focus groups and cultural probes to develop persona based scenarios. These scenarios helped to formulate a set of requirements that the potential users expect in such devices. These requirements serve as the basis for our first design iteration. The resulting prototype will be subject to two formative and a summative evaluation phases involving the potential users and therapists. Therefore, the user is an active participant within the design cycles.

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III. User Requirements

In the first phase of our design process, a review of the state of the art involving task analysis, exclusion audit and studies by the SCRIPT consortium helped to form a comprehensive but non-exhaustive list of requirements. In this section, we discuss these requirements and their methods of evaluation.

Fig. 1. Early prototype showing the device's independence from changing CoRs of the index finger during flexion and extension

A. Functional requirements

1) **Adjustable functional assistance.**
Patients with hemiparesis experience hyperflexion (increased involuntary flexion) in their hand joints, often leaving them with a closed fist and fully flexed wrist. They require assistance with extension to overcome the hyperflexion. The magnitude of assistive forces required, depends on user's motor deficit and varies with training due to the underlying recovery. Based on therapists' feedback, a maximum extension force and torque of $10\,\mathrm{N}$ and $1.5\,\mathrm{Nm}$ can be applied at the fingertips and wrist respectively. Using the spring's stiffness and joint angle feedback, achieving this requirement can be verified using a force sensor as described in [8].
2) **Range of motion for Activities of Daily Life.**
The device should allow for training over the entire range of motion (RoM) required to perform ADL as established from the literature (Table. I).

TABLE I
RoM TO PERFORM ADL

	Wrist	Fingers			Thumb	
		MCP	PIP	DIP	MCP	PIP
Flexion	70°	90°	100°	80°	100°	80°
Extension	60°	0°	10°	0°	0°	10°
Abduction	20°	25°			50°	
Adduction	30°	0°			0°	

3) **Does not hinder any of the natural range of motions of the joints.**
The device should not block any unassisted(Abduction/Adduction) DoF required to perform ADL (Table. I). This ensures that using the device does not lead to muscle atrophy.
This and the previous requirement (No 2.) will be evaluated by measurement of the joint angle using a goniometer and a data glove.
4) **Self-aligning centre of rotation (CoR).**
The CoR of the joints varies with hand movement. Misalignment between the CoR of the user's joints and those of the device would lead to the user's discomfort. Hence the device/orthosis needs to allow for alignment with the hand's CoR (Fig. 1). Our design eliminates this concern using a flexible interaction element.
5) **Measurement of finger and wrist motion.**
Measurement of the flexion and extension angles of the fingers and wrist is necessary for the user and the therapists to monitor the training progress. These measurements can also be used to control therapeutic interactive games. These have been shown to improve user's motivation. SCRIPT researchers evaluated the repeatability of their joint angle measurement using four different standardised grip sizes. We aim to evaluate our prototype using the same approach and a goniometer.
6) **Accommodate different hand dimensions.**
A device that is customised to the user's hand-size is preferred since a mismatch in dimensions leads to discomfort and render it bio-mechanically inefficient. Hence the design has to adapt to different hand dimensions. A qualitative evaluation regarding any discomfort while training, involving multiple users with different hand sizes will be used to validate this.
7) **Visual and tactile transparency**
Wearable hand devices often block fingers' tactile sensing and restrict the visibility of the hand. The ability to observe grasping and movement of the fingers and wrist and feel the tactile features of the interacting object adds to this sensory stimulation and neural modulation potential. The functional element, achieving tactile and visual feedback is considered within the design cycles, while usability elements are subjectively evaluated.

B. Usability requirements

8) **Ease of donning/doffing.**
This is one of the most significant requirements of all, since the users experience deficits in their motor function. Therefore, the design should allow the user to don/doff independently with ease.
9) **Safe to use at home.**
Given the absence of a clinician's supervision, the device should pose no risk of injury to the user and the family members.
10) **Smaller space requirement and increased mobility.**
Based at home, the device should occupy less space to ensure use-as-needed. Location flexibility could reduce mental/emotional fatigue which in turn could lead to longer training duration.
11) **Require relatively less technical proficiency to operate.**
Easy, infrequent and short procedures for setting up, operating and troubleshooting helps with maintaining the motivation levels of the user.

Given the subjective nature of these requirements (Nos 7-11), a qualitative evaluation involving clinicians and stroke survivors with Likert scale questionnaires will be used to study the usability of the device. This requirement analysis showed the significance of wearability and usability in user's acceptance and hence required a major part of our focus.

IV. CONCLUSION

A prototype has been developed according to the above mentioned requirements and is ready to be evaluated against them. The results of this formative evaluation will help to update both the design and the underlying initial set of requirements. The resulting second iteration of the prototype will undergo further evaluation involving potential users, to validate its functionality and usability.

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