An ergonomic solution for hand rehabilitation product design for stroke patients

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Abstract. Rehabilitation training is a crucial part that helps stroke patients to train their muscles and rebuild the connection between muscle, nervous system and brain. This study conducts an ergonomic redesign of hand rehabilitation products based on the interview investigation to the user behavior and psychology during the training rehabilitation. The driving part of the device was relocated from the palm to the back of the hand to enhance the experience of stroke subjects to grab objects. Moreover, the device can drive the user to have a positive attitude towards their rehabilitation by visualizing the training improvement. Body scan and 3D printing technologies were utilized to ensure the accuracy of the position of the electric stimulation pads on the hands. The design also enhanced the voluntary motor functions at the palm and the fingers. The research results will contribute in formulating the design criteria of hand rehabilitation training products for stroke subjects.

Keywords: Hand rehabilitation, Ergonomics, 3D scanning, Product design

1 Introduction

Stroke is a common disease that occurs among the ageing population, especially for people who are older than 64 years [1]. As an ageing society, Hong Kong is expected to have an increased number of stroke patients in the future [2, 3]. Stroke is a disease that causes disability after the incidence [1]. The high proportion of stroke patients experience serious suffering due to the impact of an instant drop in intellectual and physical capability, which is also very likely to affect their families [4]. A systematic solution is urgently needed to enable patients to go back to healthy, efficient and comfortable living without affecting their self-esteem [5].

The medical treatment procedure for stroke patients contains three stages: diagnosis, treatment, and rehabilitation [1]. Recovery is a crucial part that helps patients to train their muscles and rebuild the associations among muscle, nervous system and brain [6]. The rehabilitation training, in most cases, takes place in the hospital or clinic under the supervision of a doctor. Continuous repetition after the first six months are beneficial for recovery [6]. However, there is a shortage of public medical resources in Hong Kong, which may lead to insufficient training for patients [4, 5].

Traditional rehabilitation training methods are mainly carried out manually or through simple instruments to move or manipulate the affected body. This training method generally requires the assistance of multiple medical personnel [1]. Therefore, it is difficult to ensure the intensity and durability of rehabilitation training. At the same time, artificial rehabilitation training methods are easily affected by the subjective factors of therapists. The lack of the objectivity of training limits further optimization of rehabilitation training methods and the monitoring and evaluation of rehabilitation effects.

Electronic rehabilitation products are produced and developed to deal with the shortcomings of traditional rehabilitation training methods. It is a kind of automatic rehabilitation training equipment which combines advanced mechanical technology and clinical rehabilitation medicine. It provides advantages of mechanical equipment that is good at performing repetitive heavy work [9]. Rehabilitation robot, as an example, can realize accurate, automatic and intelligent rehabilitation training. Furthermore, improvement in approaches to rehabilitation medicine, increase the chances of patients receiving rehabilitation treatment, and improve the quality of life of patients.

Research related to rehabilitation technology rose in the 1990s. Professor Hogan's team at the Massachusetts Institute of Technology has carried out related research earlier [10]. The MIT-MANUS developed by this research team is a typical representative of the end-type upper limb rehabilitation robot. MIT-MANUS provides patients with shoulder and elbow joint exercise training [10]. A large number of clinical experiments on MIT-Manus showed that the rehabilitation robot has a positive effect on improving the upper limb function of patients [11]. At the same time, related research teams have also developed other upper limb rehabilitation products, such as the GENTLE/s developed by the University of Reading in the United Kingdom [12], and the MIME system developed by the Rehabilitation Research and Development Center in Palo Alto, California [13]. Besides, in order to make up for the shortage of the end type upper limb rehabilitation robot, which is difficult to control the human upper limb joints accurately, the relevant scholars have proposed the exoskeleton type upper limb rehabilitation robot. At present, the most typical exoskeleton upper limb rehabilitation robot is the ARMin upper limb rehabilitation robot developed by Professor Riener of the Federal Institute of Technology in Zurich, Switzerland [14]. After more than 20 years of development, many achievements have been made in the technical research of upper limb rehabilitation products. These achievements include active training, compliance control, prescription design, rehabilitation evaluation and many other technologies, which have been applied in clinical practice [15]. However, the existing upper limb rehabilitation products still have problems such as high production cost, limited application and limited rehabilitation effects.

In order to solve the above problems, researchers at the Department of Biomedical Engineering (BME) of The Hong Kong Polytechnic University have developed a new kind of robotic arm that provides self-service and upper limb mobility rehabilitation service for stroke patients [7]. The robotic arm is beneficial for muscle recovery. It guides the patient to gain the ability to grab back through a series of training towards the muscles in the arm and fingers. It helps patients to gain control of their muscles.

Their prototype provides rehabilitation training solutions mainly based on two technologies, electric stimulation and air chamber [8]. Compared with other products, the robotic arm has the merits of low production cost, small size and portability. Therefore, the new kind of rehabilitation product has wide potential applications and broad research spaces.

Based on the previous research, we have designed an ergonomic solution of hand rehabilitation product with the objective of improving user experience and training efficiency by providing a more convenient and comfortable way of donning it with improvement in positioning of the electric stimulation pads. At first, observation and interview were used as design methods for user research. It was aimed to investigate the user behaviour and psychology during training rehabilitation. These methods can also find ergonomic issues related to the rehabilitation training process. Accordingly, the design criteria were formulated, design solutions were proposed, and product prototypes were developed. This paper presents in detail the application of ergonomic principles in the design process for hand rehabilitation product for stroke patients.

2 User Research

The user research comprised two parts: (a) an observation to find design insights which based on the realistic difficulties and problems by patients in training process, and (b) an interview with user and therapist to prove design insights from part (a) and collect more information to develop the design concept.

2.1 Observation

Two rehabilitation sessions were observed that included two therapists and two patients. Patient A is a female. She is left paralyzed and lives alone with help of a domestic helper. Patient B is a male. He is left paralyzed and lives with his wife. An existing prototype was used as a basis for further improvement [8].

The first rehabilitation session was the wearing process. Two issues were identified based on the observation study. User needed to involve other persons' help (not necessarily professional) to secure the placement of the air chamber and the securing ring. Previous product requires medical profession when positioning the electrical stimulation pads. Positioning is also based on experience. The electrical stimulation pads need to be repositioned during the wearing session by a medical professional.

The second rehabilitation session was the training process. Several problems were identified based on this part. During the training, the loops holding the fingers and the airbag came off several times. The patient and the professional had to constantly reposition the securing ring in order to make sure it is at the right place, especially the position of the airbag of the thumb. The other issue was that the professional has to manually stretch the patient’s hands open since the air chamber cannot efficiently open up the patient’s hands entirely. In addition, the patient's wrists were often obviously compressed by the edges and corners of the desktop edge. Patients needed to alternate between two different arm positions to train arm muscles. Patients often miss training

opportunities due to distraction, but the equipment are not be adjusted due to changes in the patient's state.

2.2 Interview

Interviews were conducted for both the patient and the therapist to understand how they use and feel about the previous hand rehabilitation product [8]. Questions were asked about their usage experience and problems for the current product. These are some common issues collected.

First of all, they hope that the design can be improved to facilitate wearing because the patients want to do it independently. Secondly, during training, patients are required to hold firmly to locate the extensors and flexor muscle which is rather challenging for stroke patients as they have little muscle strength compared to other people. Finally, they believe that the setting of feedback will effectively assist training and increase patient training confidence.

3 Design Process and Prototype Development

Results of the user research provided valid data for design concept and prototype development. It was found that the issues of wearing style, positioning and driving mode were the most pronounced problem for users with previous products. Accordingly, the design criteria were identified to design a new rehabilitation robot arm. The rehabilitation robot arm design was firstly aimed to provide users experience for patients through better wearing style and positioning system. In addition, it aimed to enhance the training confidence by providing better feedback. The whole concept design is shown in Fig. 1.

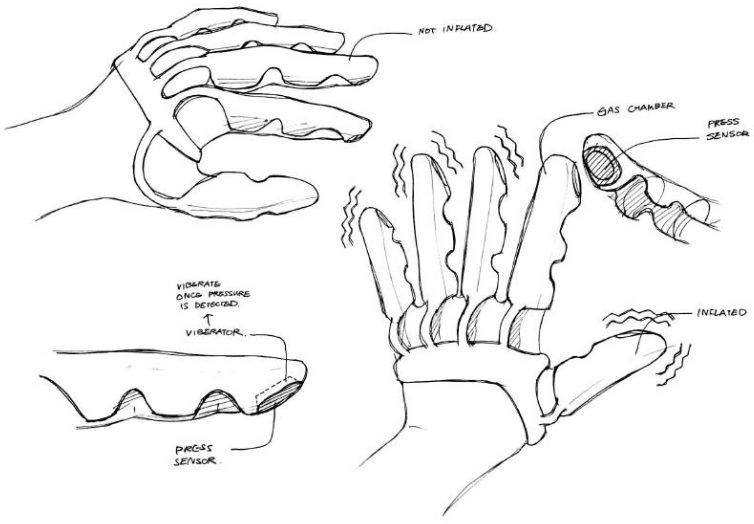

Fig. 1. Concept design demonstrating the new wearing way

3.1 3D hand data

Based on the concept design, an experimental prototype of the rehabilitation robot arm was developed. 3D scanning the hand and analyzed the surface of the side to gain data supporting from ergonomic. According to the 3D scanning data, the shape and surface of the prototype are tested and modified repeatedly to fit the hand structure. Fig. 2 showed the ergonomic data from 3D scanning.

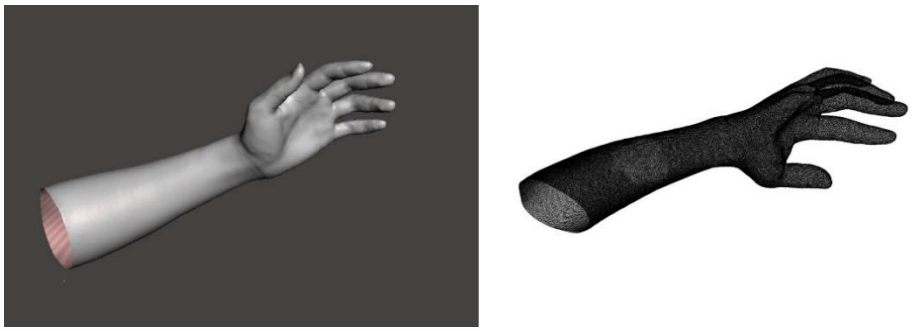

Fig. 2. The human hand data from 3D scan

3.2 Prototype developing

According to the previous user research, this research was carried on the prototype design from the following three aspects.

Firstly, the previous rehabilitation robot arm by BME is unable to provide users with enough feedback, such as grabbing and putting down objects. Taking the training of grasping and dropping objects as an example, the users need to see that they can complete and the corresponding actions. Thus they can have a sense of achievement in rehabilitation training. However, the air chamber of the rehabilitation robotic arm is inside the palm, which makes it difficult for users to train grasping objects. Therefore, in this design, the traction device is changed to the back of the hand, so that the palm can be used to practice grasping objects (see Fig. 3).

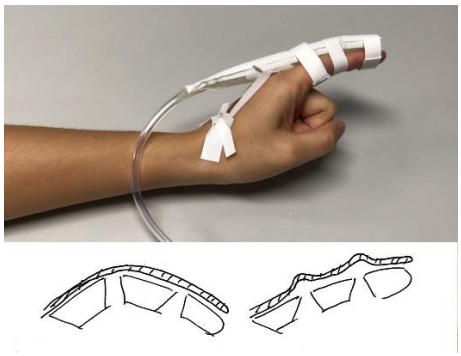

Fig. 3. The air chamber at the back

Secondly, the previous fixing method makes the airbag of the thumb part easy to rotate, which makes it difficult for the thumb to be fully exercised. At the same time, the remaining four fingers did not reach the desired extension so that the therapist needed to spread the thumb manually. 3D ergonomic data was used in this prototype design, and the product shape was designed to better fit the structure of the finger itself and have a better fixing effect.

Third, the patient needs the help of another person to wear the product in the traditional wearing style, and thus cannot complete training independently. Moreover, because the user is a patient with a long-term stroke, the muscles will be relatively strophic, so it is difficult for the therapist to identify the muscles for electric stimulation. This study developed a more accurate positioning method by considering the ergonomic structural data of the hand.

3.3 Prototype testing

Several prototypes were developed to improve the experience of grabbing objects, emulate the position of the air chamber, as well as enlarge the stretching angle. The final designed prototype was chosen to use the mechanical rope traction method for hand muscle rehabilitation training (see Fig. 4).

Fig. 4. The pulling rope type at the back

Since the patient use the existing product with the help of others, this situation increases costs and discourages the self-confidence of patients. The design concept was to experiment on the form of the rehabilitation device so that the patients can wear the hand part by themselves as well as facilitate the user to wear the electric stimulation pads without the supervision of professionals (see Fig. 5).

Fig. 5. Wearing testing

4 Evaluation of Design

Several 3D prototypes were designed then 3D printed by using 3D printing technology. 3D designed prototype (Fig. 6) including rendering can show clear structures for the new rehabilitation robot arm. Simpler design were first evaluated using test based on realistic difficulties and problems encountered by hand rehabilitation products. The results indicated that, by creating a new ergonomic dressing method that allows patients to complete rehabilitation training independently, can greatly improve the user experience, increase their enthusiasm and self-confidence in rehabilitation training, and enhance the rehabilitation effect.

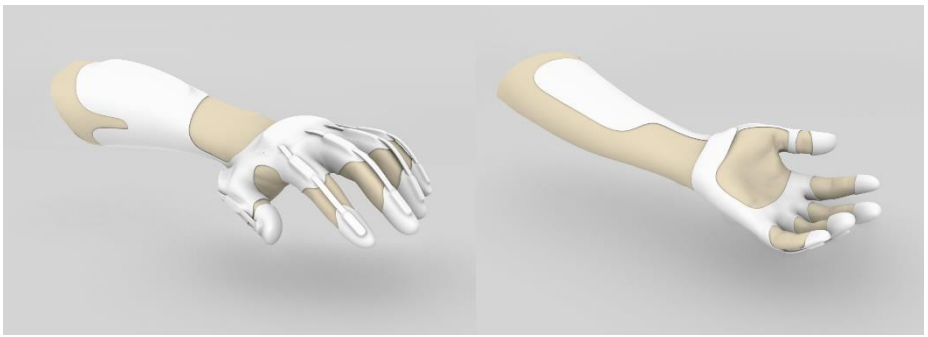

Fig. 6. Rendering of the final design

As shown in Fig. 7, the functional prototype shows the rehabilitation training driven by the electric motor and the pulling rope, the energy training process, and the intuitive feedback of the rehabilitation training effect. This result makes patients more willing to participate in treatment actively.

Fig. 7. Mechanism process

The wearing processes are shown in Fig. 8. Patients can independently complete the entire process of wearing this hand rehabilitation device. This design can greatly save labor costs.

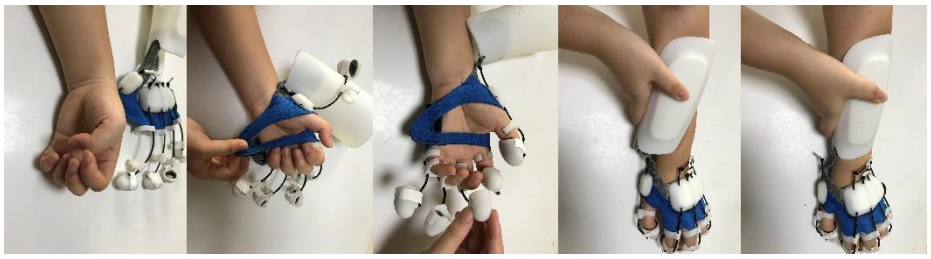

Fig. 8. Wearing process

The final prototype is shown in Fig. 9. In summary, ergonomic design solution of the hand rehabilitation product uses a new type of grasping object treatment. It can improve the user experience of stroke patients during rehabilitation training, pay attention to the psychological feelings of stroke patients, and visualize the treatment process.

This design solution can promote patients to change from passive treatment to active treatment, which greatly improves the patient's self-confidence and dignity.

Fig. 9. Final prototype

5 Conclusion

This study mainly focuses on an ergonomic redesign of hand rehabilitation products with the objective of improving the user experience of hand rehabilitation training for stroke patients. The design relocated the driving part from the palm to the back of the hand to enhance the experience of stroke subjects to grab objects. According to the interview, patients mentioned that the improvement highly motivated them. By visualizing training improvement of patients, the device can drive the user to have a positive attitude towards their rehabilitation. The project also utilized 3D scanning and 3D printing technology to ensure the accuracy of the position of the electric stimulation pads on hands. The voluntary motor functions at the palm and the fingers could be enhanced by the rehabilitation training. These results will help in formulating the design criteria of hand rehabilitation training products for stroke patients.

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