DESIGNING AND EVALUATING A WEARABLE sEMG DEVICE FOR THE ELDERLY

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ABSTRACT
As muscle and strength decline with age, the risks of falling down and becoming disabled increase for the elderly. However, rehabilitation for patients through long-term treatments and assessments in medical institutions take a long time. It reduces the elderly people’s quality of life and causes a burden on their living and financial on their family. Therefore, the goal of this study is to design the wearable sEMG device based on wireless sensing technology for muscle rehabilitation. We aim to help the elderly train their lower limbs at home and simultaneously collect physiological signals though training for remote medical diagnosis. In this study, the design direction is established through focus group interviews. The rehabilitation actions were observed, and the position of muscle movement was measured to establish design parameters and procedures. The designed wearable device was evaluated through a pilot study and semi-structured interview to understand its usability and feasibility. Finally, experts evaluated the usability of the device. From the results, it was found that rehabilitation at home using the designed wearable sEMG device was accepted by most of the elderly respondents. They think that it is very convenient to receive medical feedback at home. Furthermore, medical staff can also use the physiological data to understand the patient’s condition and provide diagnosis and treatment. We hope that the product can be widely used to receive signals of the rehabilitation of elderly’s lower limb muscles at home in the future. Further discussions on the design implications of the development process can be a reference for future related product development.

KEYWORDS
sEMG, Wearable Device, Lower Limbs, Elderly, Usability

1. INTRODUCTION
Many studies have confirmed that weakness is highly correlated with loss of muscle strength and is more likely to result in falls and disability (Cruz-Jentoft et al. 2018). Daily strength training and rehabilitation therapy are effective ways to prevent or improve muscle weakness (Ouellette et al. 2004). In the current medical form, patients need to go to medical institutions for regular rehabilitation treatment and muscle recovery tracking. This reduces the elderly’s quality of life and causes a living and financial burden on their families. Moreover, as the elderly population grows, medical resources are becoming insufficient, which is inevitably making the development of smart medical care a trend nowadays.

In the medical rehabilitation industry, the application of smart wearable devices has risen with the development of wireless sensing technology. The goal of telemedicine is to upload the surface electromyography (sEMG) signal to the cloud for medical staff through a sensor for diagnosis and treatment. Among them, wireless sEMG signal sensing wearable devices are an important element of development.

The lower limbs of the human body include the hips, knees, and ankles, which account for about 70% of the body. It supports normal walking, running, jumping, and other sports. Furthermore, the interaction of lower limb muscles and joints is very important for the balance and stability of the human body (Kuruganti et al. 2006). Elderly people have a 15% to 40% chance of falling each year, and the chance of injuries to upper and lower limbs is about 70% (Hartholt et al. 2011). A number of studies have shown that the forward impulse causes the elderly to fall, which is the most common type of fall among this demographic (O’neill et al. 1994). It usually causes serious damage to the head and limbs (DeGoege et al. 2003). Moreover, injuries to the lower limbs restrict the movement of the elderly, who could feel inferior due to disability. The elderly experience a sense of inferiority when they cannot live on their own (Pizzigalli et al. 2011).
The goal of this study is to design a wearable sEMG device for the rehabilitation of the lower limbs of the elderly at home. The design focuses on the following four points: (1) the surface EMG patch must be placed in the correct muscle position; (2) the needs of rehabilitation and medical treatment must be met; (3) the principles of human factors engineering must be complied with; and (4) the process flow must be smooth.

Our study contributes to the literature in three ways: (1) We design a wearable sEMG device which can be used for the muscle rehabilitation of the lower limbs of the elderly to obtain specific muscle’s sEMG signals. (2) We establish design requirements through wearing behavior research. (3) We attempt to understand the elderly’s acceptance of designed wearable sEMG devices.

2. RELATED LITERATURE

The goal of this study is to design a wearable sEMG device for the rehabilitation of the lower limbs of elderly people at home. We focus on the usability of wearable devices for the elderly and the application of sEMG in the market in the literature review.

2.1 Technology and Interfaces for the Elderly

Physiological monitoring and disease prevention are the main applications of wearable devices for the elderly (Kekade et al. 2018). Previous studies are mostly related to technology development. After the sensing technology becomes mature, we then pay attention to improving the feasibility of the practical applications of the technology. It is necessary to consider that more problems may be encountered when operating wearable devices due to a decline in cognition and various physical functions (Li & Luximon 2016; Rodriguez et al. 2017). Many studies have pointed out that elderly people can accept health tracking by wearing devices (Batsis et al. 2016; Mercer et al. 2016). Elderly people’s willingness to use wearable devices is affected by their usefulness and comfort of use (Bodine & Gemperle 2003; Keogh et al. 2020). The design should avoid multiple tasks at the same time (Verhaeghen et al. 2003). In addition, the elderly have their own special subjective consciousness (Abbate et al. 2014). Therefore, the design of a wearable device for the elderly not only needs to meet technical feasibility, but also consider the physical and psychological factors of their elderly users.

2.2 sEMG Signal Application

Surface electromyography (sEMG) is a bioelectric signal generated by the nervous system during muscle contraction. It is usually recorded in pairs or multiple potentials, and the difference between the two potentials is amplified and recorded. The sEMG signal can track the exercise frequency and intensity of the elderly, and the activity state of their muscles during rehabilitation (Chen et al. 2019). It has been proven by clinical research as an effective evaluation of coordinated exercise and treatment effect (Rainoldi et al. 2004). Although a large number of studies have confirmed the feasibility of its clinical application, the technology has problems it needs to address in its medical applications. For example, the part of the skin touching the sensors must be cleaned before being tested and action posture must be corrected during the test (Falla et al. 2002). The sensor structure must comply with the following basic regulations: (1) the myoelectric sensor direction should be parallel to the muscle fiber; (2) the ground terminal should be perpendicular to the myoelectric sensor; and (3) the distance between the centers of the two electrodes should be about 20mm. In order to ensure the stability of the signal, a gel-type Ag/AgCl electrode should be used to contact the skin’s surface, and a light-weight material should be used to fix the sensor to avoid artifacts when receiving the signal (Hermens et al. 2000).

The MYO gesture recognition armband was developed by Canada’s Thalmic Labs in 2013. It uses a myoelectric sensor and nine-axis detector to detect more than 20 hand movements for controlling computer games, robots, a mouse, and more (Benatti et al. 2014). In addition, the smart fitness clothing developed by Athos has a total of 26 sEMG and heart rate sensors to monitor muscle fatigue as a judgment for sports injury prevention. According to the above two examples, the combination of surface myoelectric signals with wearable devices does have potential for development. However, there is still a big gap in the precision of receiving signals in medical applications. With the gradual rise of telemedicine, it is estimated that wearable devices combined with surface myoelectric signal sensing will be widely used in medical treatment in the future. Therefore, the goal of this study is to design a wearable sEMG device for muscle rehabilitation that helps the elderly to train their lower limbs, and simultaneously collects physiological signals though training for medical diagnosis.
3. METHOD

In this section, we thoroughly explain how to determine the design criteria and describe the overall design process of the wearable device. Finally, the appropriate methods of designing the wearable device are detailed.

3.1 Focus Group Interview

In this study, a focus group interview was conducted with three professionals from the fields of medicine and industrial design, and three elder people. We discuss the content of rehabilitation medical care, human factors engineering design and physical psychology of the elderly, then determine the goal of the wearable design. Some statements are given followed by four conclusions: (1) Common training muscle groups required for complete lower extremity rehabilitation include quadriceps, tibial anterior, gastrocnemius, soleus. It effectively improves muscle endurance and reduces degenerative-related nervous system pain. (2) For patients with degenerative neuritis, the four major muscle groups are usually trained with knee extension, dorsiflexion, and plantar flexion. (3) Since the position of the muscles of the lower limbs differs depending on the individual’s height, weight, subcutaneous fat, and other factors, an adjustable design should be considered to increase the accuracy of physiological signal detection. (4) It is necessary to use a sEMG patch to receive the accurate sEMG signal.

3.2 Implementation

This section divides the wearable device design process into two parts: (1) establishing design criteria and (2) wearable device design process. The following is a detailed description based on the design steps:

(1) Design Criteria
   Based on the focus group interviews and related works, three design criteria were summarized:
   A. The myoelectric sensor should be attachable to the best sensing position of the target muscle group.
   B. The wearable device should be fixed on the body for it to function smoothly during rehabilitation.
   C. The sensor is designed to be easy to remove and clean since the wearable device needs to be cleaned regularly.

(2) Circuit Components-Muscle Sensor
   The circuit components for sensing myoelectric signals were made by the ready-made MyoWare muscle sensor modules. We used the potential difference to judge the position of muscle movement and the degree of force, combined with the nine-axis accelerometer to judge the direction of movement. Then, with Arduino software for programming, we used the surface electrode patches to measure sEMG signals. They were processed by the amplifying unit, using Wifi to connect the ready-made Unity software to transfer the potential values.

Figure 1. Schematic diagram of the hardware circuit
(3) Wearable Device Design Process

Conceptual development. At this stage, two design plans are proposed according to the design criteria: (1) the first type of design is that the sensor is embedded in the wearable device; and (2) the second type is the detachable sensor design.

![Figure 2. Sketch description. (a) The first type of design is that the sensor is embedded in the wearable device. (b) The second type is the detachable sensor design](image)

Design decision. Iterative design was carried out according to the evaluation results of the prototype. The detailed design description of the wearable device is as follows:

A. Wearable device design: The wearable device was designed to be composed of the upper and lower parts (Figure 2.). In addition to easily adjusting the position, each rehabilitation may only train one muscle group, so the unused parts can be removed. The part of the wearable device that is in contact with the skin needs to be cleaned regularly; thus, cloth material is used, and the sensor is designed to be detachable. The middle round hole is used as a calibration point for the user’s knee (Figure 2. (a)). The black circles on two parts of the wearable device are where the quadriceps, tibial anterior, and gastrocnemius sensors are positioned (Figure 2. (b)-(d)).

![Figure 3. Wearable device design](image)
B. Size adjustment design: The quadriceps position is found to the left and right sides about three fingers above the knee; the tibial anterior is in the front part of the middle lower leg; and gastrocnemius muscles is in the back part of the lower leg. The wearable device is adjusted by the belt to control the size and position of the sensors. Moreover, a tick mark on the wearable device records the position for finding the correct location faster when users wear it next time.

C. Sensor design and instruction recognition: The sensor was designed in the shape of a water drop, and the its sharp corners are used to indicate direction (see Figure 2. (f)). When the sensors are attached to the corresponding orange color block, the three buttons below them can be aligned with the three small round holes of the EMG patch on the wearable device. The devil felt can be used to attach the sensor to the wearable device(see Figure 2. (f)-(g)). This fool-proof design allows users to operate the device more smoothly.

4. PILOT STUDY DESIGN

As the basis for future product development, we aimed to understand the usability of the wearable device through a pilot study. The designed wearable device was evaluated through a wearing behavior test and user study to understand the using situation. The detailed descriptions of the experiments are as follows:

4.1 Wearing Behavior Test

The wearing behavior test confirms the expected effect, understanding the problems that may occur during the experiment, and establishes the purpose of observation. Therefore, three males and females who have never used the wearable device are recruited for the test. First, the researchers explained and demonstrated how to wear it. Second, it was operated by the test subject. Third, the subject was required to perform lifting, tipping, and hooking three lower limb rehabilitation actions. Finally, a semi-structured interview was conducted to understand the subjective thoughts, willingness to use, and problems encountered by the elderly in the process of wearing the wearable device. Each subject took about 15 minutes for the experiment.

Three key points of design adjustment were observed from the wearing behavior test: (1) the direction of the combination of sensors, wearable device, and EMG patch should be clearly marked; (2) the operation steps should be appropriately marked on the wearable device; and (3) instructions and assistance are required when conducting user study for the elderly.

4.2 User Study

Participants

Eight participants with an average age of 70.5 were recruited in the community center. All participants have the ability to perform simple movements with their lower limbs, have normal cognitive ability, and are able to clearly express their thoughts. In order to ensure the smoothness of the experiment, a social worker from the institution and two researchers were present to assist.

Procedure

First, the researchers explained and demonstrated how to wear it. Second, the device was operated by the test subject. Third, the subject was required to perform lifting, tipping, and hooking three lower limb rehabilitation actions. Finally, a semi-structured interview was conducted to understand the subjective thoughts, willingness to use, and problems encountered by the elderly in the process of wearing the wearable device. Each subject took about 15 minutes for the experiment.
5. RESULT AND DISCUSSION

Based on the results of the thematic analysis of the interview, this chapter is divided into two parts: (1) wearable device usability and (2) expert feedback for discussion. The following are detailed explanations:

5.1 Wearable Device Usability

The usability of this wearable device is discussed in three parts: (1) wearable device operation; (2) rehabilitation with the wearable device; and (3) the willingness of the elderly to use the wearable device. As for the operation of the wearable device, the design with two detachable parts has a higher degree of freedom when being operated. However, too much adjustment will make the user feel confused while wearing it. To allow users to operate the device themselves, we designed different shapes, colors, and other fool-proof mechanisms on the wearable device for their ease of use. According to the current design, young people can easily wear them by following the instructions. On the other hand, while a single step can be successfully completed by the elderly, they still need assistance on the overall process of wearing the device because of the integration steps. We will reduce adjustable places and simplify operational steps in future works. In terms of rehabilitation with the designed wearable device, majority of the subjects showed positive reactions in wearing comfort. One subject is an extreme case in size. He feels the device is too small to wear and can bring discomfort when performing an action. Therefore, the size adjustment step needs to be enlarged. There was another subject who caused the positioning point to shift due to wearing errors. In terms of willingness to use, three elderly people expressed their willingness to use this product, and the other three indicated that they would use the products if the steps for wearing can be simplified. The six test subjects thought it was very helpful to save time for rehabilitation in a medical institution, and the other two subjects thought that they could perform well without this wearable device.
Figure 5. The lower limbs wearable sEMG device featured in this study

5.2 Expert Feedback

We invited the attending physicians of the Rehabilitation Department of the National Cheng Kung University Hospital in Taiwan to conduct expert interviews and give suggestions on the designed wearable device. Dr. Lian gave a positive response to the design concept of this product. In terms of the human-related design of wearable devices, although the medical staff can easily adjust according to different patient conditions, elderly people with severe decline in cognitive and physical functions may increase operational errors due to the multiple steps. Therefore, we should increase the fool-proof mechanisms to avoid errors in wearing the device. In terms of human body measurement, as muscle and strength decline with age, the measurement position and muscle size of the elderly vary more than those of young adults. It is recommended to recruit more elderly people for the measurement. Besides, this wearable device is mainly used for long-term muscle rehabilitation. It is necessary to increase the strength of the mutual combination of each part.

6. CONCLUSION

The study aims to design the wearable sEMG device of muscle rehabilitation, which helps the elderly to train their lower limbs, and simultaneously collect physiological signals though training for medical diagnosis. It can not only save patients time spent in visiting medical institutions for rehabilitation, but also solve the shortage of medical resources. To collect clinical pain points, focus group interviews were conducted to determine the value of development and design requirements. The design is based on medical restrictions and human factors engineering. Since the wearable device needs to be cleaned regularly, the sensor was designed to be detachable from the wearable device. To increase the degree of freedom of position adjustment, the sensor is composed of two parts; the upper part of the wearable device is used to sense the electromyographic signals of the quadriceps, and the other part is used to sense the electromyographic signals of the tibial anterior and gastrocnemius. In addition, considering the decline of the cognitive ability of the elderly, we designed different shapes, colors, and other fool-proof mechanisms on the wearable device as reminders. After designing the wearable device, we conducted a two-stage pilot study to evaluate the usability of the designed wearable device by the target group. In the future, we will improve the current wearable devices based on the results. The three noteworthy points regarding the design of the device are as follows: (1) elastic structures must be added at specific locations of the wearable device to increase strength; (2) visual recognition must be increased to reduce the wearing error rate of the elderly; and (3) adjustable places must be reduced and the sticking direction of the devil felt must be unified to improve the integrity of the wearable device.
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REFERENCES


