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Proceeding Paper

Design and Test of E-Textiles for Stroke Rehabilitation †

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Abstract: This work presents the design and test of an e-textile based functional electrical stimulation system for post-stroke upper limb rehabilitation. The prototype was tested on five stroke survivors to assess stimulation comfort, the stimulation intensity required to achieve hand opening, and ease of use. Wrist extension was measured using two inertial measurement units. The wearable e-textile prototype achieved similar stimulation comfort compared to high-quality hydrogel electrodes with a score difference of between 0 and 1. The stimulation intensity to achieve full hand opening was the same for the hydrogel electrodes and the e-textiles for all five participants. A second design based on a knitted sleeve has been assessed in terms of usability. Additional new designs have been proposed to improve the usability.

Keywords: electrode; functional electrical stimulation (FES); inertial measurement unit (IMU) stroke rehabilitation; e-textiles; healthcare

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1. Introduction

Stroke occurs when there is a blockage or bleeding of the blood vessels affecting the supply of blood to the brain. There are 1.3 million stroke survivors in the UK [1] and stroke costs the UK National Health Service and wider society £26 billion per annum [2]. Over half of stroke survivors have weak arm/hand movement affecting their independence and quality of life. Functional Electrical Stimulation (FES) is a technology used for stroke rehabilitation. It applies a safe electrical impulse through electrodes placed on the skin to strengthen weak muscles and improve movement functions. FES has been used to exercise muscles and assist walking for people with mobility issues since the 1960s [3]. Systematic reviews with meta-analysis have concluded that FES improves the ability to perform activities [4–6]. Existing FES products are difficult to set-up by stroke survivors without help from their carers or healthcare professionals which significantly constrains usage. Our previous work has received positive feedback regarding wearable e-textile FES for home-based stroke rehabilitation [7]. This work presents the test results of a fabric electrode based wearable FES in terms of user comfort, stimulation intensity, and functional movement (wrist extension for hand opening) on five stroke survivors (ethics approval ID: University of Southampton ERGO 70296). Ease of use has been assessed. A second knitted design has been assessed and additional new designs to improve the usability have been proposed for future study.

2. Materials and Methods

2.1. Electrodes

Wearable electrodes (5 cm × 5 cm) were fabricated by stacking in turn: a non-woven fabric, conductive wires leading to a connector, a conductive carbon film and a carbon rubber electrode layer. Encapsulating the edges holds the entire assembly together. The electrode was attached to a fabric arm band as shown in Figure 1. The wearable electrodes were compared with commercial high quality hydrogel electrodes (PALS, Axelgaard, Fallbrook, CA, USA).

(**a**) (**b**) (**c**)

Figure 1. (**a**) fabric electrode arm band. (**b**) fabric electrode arm bands being worn by a stroke survivor. (**c**) hydrogel electrodes being worn by a stroke survivor.

2.2. FES

The OML Microstim 2V2 neuromuscular stimulator (Figure 2) was used in this study. Stimulation was set-up by a clinician to optimise the electrode positions and stimulation intensity. Water was sprayed on the electrodes and the skin before applying the fabric electrode to improve user comfort and stimulation effectiveness. Stimulation comfort was rated in a scale from 0 to 10 with 0 is the most comfortable and 10 being very painful. The stimulation intensity was recorded.

Figure 2. OML Microstim 2V2.

2.3. Inertial Measurement Unit (IMU) Sensors for Wrist Bending Measurement

The wrist angle was measured using a pair of BNO055 IMU sensor breakouts from Adafruit (Figure 3) which reports the absolute angular position of the sensor. The IMUs were attached to the user by using Velcro straps with one attached to the hand and the other to the arm. An Arduino Micro was used to gather the data from the sensors and sent it to the computer recording the data. The computer then calculated the wrist angle by taking the difference between the two absolute positions from the sensors.

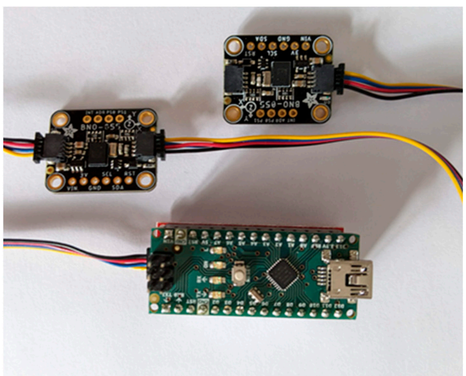


Figure 3. BNO055 IMU sensor.

2.4. Usability Test

Participants were asked to put on and take off both the hydrogel electrodes and fabric electrode arm bands to assess their capability of using the products independently.

3. Test Results and Discussion

Five participants were recruited for the testing. Age: 56–76, Years of stroke: 3–17 years. Genders: 1 female and 4 males.

3.1. Stimulation Comfort

All participants reported the same or similar stimulation comfort with only 0 to 1 score difference between the two electrode types as shown in Table 1. One participant (P1) reported the fabric electrode was more comfortable than the hydrogel electrodes. One participant (P4) reported the same comfort scale. The other three reported the hydrogel electrodes were more comfortable than fabric electrodes. No pain sensation was reported.

Table 1. Stimulation comfort scale results by participant.

Participant	Hydrogel Electrode	Fabric Electrode
P1	3	2
P2	2–3	3
P3	5	6
P4	5	5
P5	2–3	3–4

3.2. Stimulation Intensity

There was no difference in the stimulation level required to achieve full hand opening between the two types of electrodes (Table 2). The required stimulation levels vary from 40 mA to 50 mA. This indicates the fabric electrodes were as effective as the hydrogel electrodes in generating a functional movement.

Table 2. Stimulation intensity required to achieve hand opening.

Participant	Hydrogel Electrode	Fabric Electrode
P1	50 mA	50 mA
P2	40 mA	40 mA
P3	40 mA	40 mA
P4	50 mA	50 mA
P5	45 mA	45 mA

3.3. Wrist Bending Measurement

Wrist movement was measured during the stimulation. All participants achieved a similar movement for the two types of electrodes. Figure 4 is a representative example of the wrist bending angle for the two electrode types.

3.4. Usability

Researchers observed that it was a challenging task for participants to peel off the hydrogel electrodes from the protective plastic film because the hydrogel electrodes are very sticky. It was even more challenging for them to take out the electrodes from the sealed bag and put them back after use. With the electrode arm band, although all participants were able to put it on and take it off independently, they found it challenging to keep the electrode in place because it moved around before it was fastened and secured in place. In addition, it was challenging to put the Velcro hook fastener through a loop. All participants were able to spray water on the electrodes and the arm using a single hand.

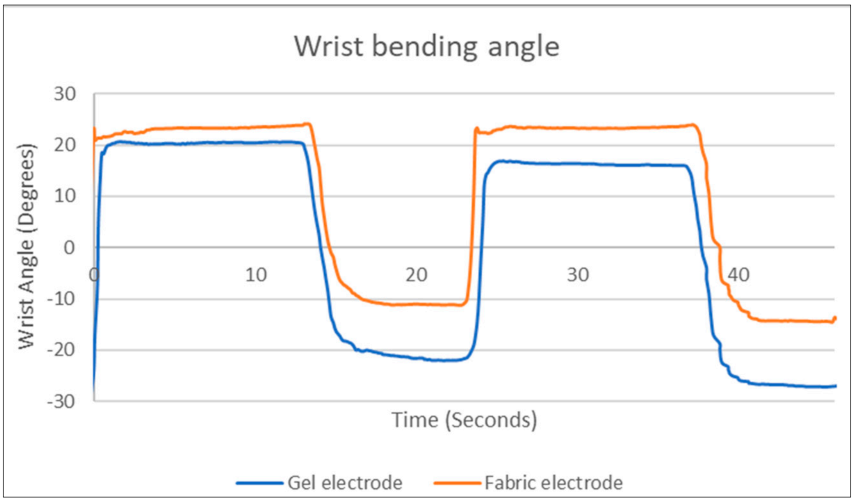
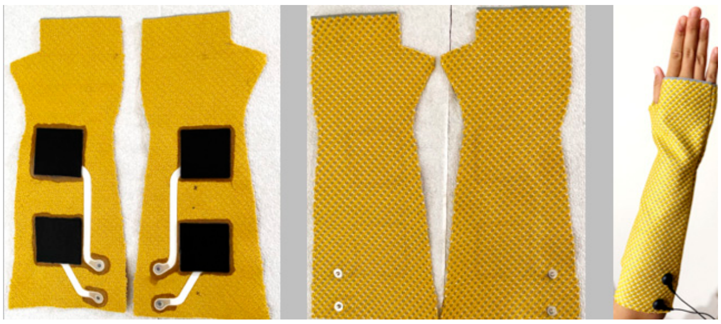


Figure 4. Wrist bending angle.

3.5. Second Design: Knitted Sleeve

Two pairs of electrodes were printed on a knitted fabric made of wool and Lycra yarns to stimulate muscles for both hand extension and flexion (Figure 5). The electrode fabric was assembled to form a pull-on sleeve. It was noticed the electrode sleeve was difficult to put on or take off because of the strong friction between the electrodes inside the sleeve and the skin. Discussions with the stroke survivors have indicated that an open, or partially open structure, would allow the user to put on the electrode sleeve easily, then tighten the sleeve to ensure the electrodes and skin contact sufficiently.



(**a**) (**b**) (**c**)

Figure 5. (**a**) electrodes printed on knitted fabric. (**b**) electrode fabric with snap buttons. (**c**) electrode sleeve worn on an arm and connected to a stimulator via snap buttons.

4. Conclusions and Future Work

This work has demonstrated the stimulation comfort and functional movement delivered by a wearable e-textile activated with the OML FES stimulator Microstim 2V2. The fabric electrode achieved similar stimulation performance while providing the advantage of being suitable for wearable application and offering a long service life. All participants were able to put on and take off the fabric electrode arm bands independently, but it is time consuming and a better design is required. A new design with electrodes printed on a knitted stretchable sleeve was investigated but it was difficult to put on and take off due to the friction between the electrodes inside the sleeve and the skin. New designs, required to improve the ease of use, will be addressed in future work.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: No new date was created.

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Conflicts of Interest: The authors declare no conflict of interest.

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