A Finger Movement Evaluation Device to Monitor the Use of Paretic Hand During Daily Life Activities

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Abstract— Hand movement tracking devices are important to monitor impaired hand function during daily activities. The study presented in this paper investigates the feasibility of using a hand glove device to monitor the use of paretic hand in daily life. A Finger Movement Evaluation Device (FMED) was developed for this purpose and it was tested on six stroke subjects who used it for two days. FMED records the flexion angle of two metacarpophalangeal (MCP) joints (for example, index and middle MCP joints). A questionnaire was used to evaluate subjects' acceptance of FMED. Data collected by FMED were analyzed to calculate the ratio of finger movement episodes during the day and amount of movement as a sum of individual movement episodes. Results showed a high satisfaction of patients and the ability to acquire quantitative information about the quality of movement while using the device; these results concluded that FMED is a promising tool to monitor the use of impaired hand in real life whether as a regular routine test or as part of a home based therapy set up.

Keywords- hand glove devices; movement impairmemt; stroke

I. INTRODUCTION

Stroke is the major cause of neurological disability all over the world [1]. However, upper extremity (UE) motor impairment, specifically hand paresis, is the most disabling and persisting residual impairment after this event [2], and it is evident that it limits basic activities of daily living [3]. For this reason, the role of stroke rehabilitation is to promote the independence in daily life activities [4]. Moreover, the use of outcome measures (OMs) in neurological physical therapy is essential to evaluate the improvement of function during rehabilitation [5]. So, an essential issue in the assessment after stroke is to determine how much the impairment of upper extremity is the source of loss of function, and if the selected rehabilitation intervention improves the activities of daily life of stroke survivors.

Numerous standardized clinical measures are available for clinicians to evaluate UE function after stroke. Yet, these measures are rarely used in clinical practice because of time constraints, high level of difficulty, lack of equipment, and lack of knowledge regarding OMs [6]. Besides, most of these measures do not collect information about the use of UE in the Activities of Daily Living (ADLs) and they do not provide clinicians with quantitative and objective information about patients' use of impaired limb during the day [7]; thus, they do not reflect how the patients interact in their daily life and their real world [8]. The use of assessment tools at home and community is essential to evaluate the UE function during daily activities in order to improve therapeutic intervention and avoid having patients stop using the impaired limb due to pain or absence of confidence and eventually losing the ability to use it due to the learned non-use phenomena [9].

Wearable measurement devices and home monitoring devices provide clinicians with additional assessment opportunities like collecting hand posture and movement data as individuals perform daily activities outside the clinic [10]. Despite their importance in measuring fingers' range of motion during dynamic tasks [11], different limitations exist; they are expensive, heavy and uncomfortable to be worn in daily life outside the clinic [12, 13] , and do not provide long term monitoring [12].

Preliminary research in the area of hand glove devices has focused primarily on testing protocols that evaluated glove devices characteristics [10-12, 14-17] and none of them has explored the use of these devices to monitor the impaired UE function during daily life.

This article describes the design of a low cost device for the assessment of finger's movement during daily activities. Section II describes the device design and implementation, Section III describes the feasibility study

methodology. Sections IV elaborates on the results and discussion, followed by conclusion in Section V.

II. METHODS

A. Finger Movement Evaluation Device (FMED)

The Finger Movement Evaluation Device (FMED) was designed to act as an offline electronic goniometer that measures finger flexion angle of 2 joints simultaneously. It includes two bending sensors (SpectraSymbol®, UT, USA) that can be placed on two fingers' MCP joints (for example index and middle fingers) at a time using Velcro™. Only 2 joints are tracked in order to reduce the cost of the device letting the user focus on two fingers at a time with the flexibility in choosing which joints to track.

Figure 1 illustrates the main parts of the device. A voltage regulator circuit was implemented to down regulate the power from a 12V (6500 mAh) rechargeable battery to 5V. A dc-dc converter was implemented before the voltage regulator to convert 12V to 7V in order to avoid too much heat dissipation in case of using the voltage regulator to down-regulate from 12 to 5V. A charged battery (12V, 6500 mAh) can power the device for more than 48 hours.

The microcontroller (ATmega2560) reads input from the bending sensors through a voltage divider signal conditioning circuit. This is a low-power complementary metal–oxide–semiconductor (CMOS) 8-bit microcontroller that supports a real Read-While-Write Programming mechanism. The microcontroller processes the data, and saves the values of each joint on an SD card in real time. The raw data are saved on the SD (Secured Digital) card in addition to the fractionation angle (difference in angle between the two joints). This device also gives patients a real-time feedback of their movement using a set of light emitting diodes (LEDs) indicating the level of fingers movement flexion with increments of 10° (10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°) and fractionation with increments of 5° (5°, 10°, 15°, 20°, 25°). The main electronics of the device was chosen to be surface mounted in order to reduce the size and weight of the device. FMED weighs 1.3 kg with battery. Figure 2 shows FMED worn by a volunteer.

B. Collected Data

As mentioned in the last section, the device saves the values of the variation of angles for sensors 1 and 2 (for example, index and middle finger flexion angles) and the individuation (difference between angles recorded by sensor 1 and sensor 2) versus time. A customized Matlab® algorithm was written to process these data. The first processing step was to calculate differences between adjacent elements of the dataset in order to detect movement episodes (change in flexion and individual angles). A threshold of 2° was used to count the episodes of movement (flexion angle exceeding a 2° predefined threshold). The ration of counted samples over whole dataset provided the Ratio of Movement (RaOM) values of each finger.

The other parameter that was calculated is related to the mean of difference in the angle between the two fingers (individual finger movement). Episodes or consecutive samples where there was a difference in flexion between index and middle fingers were reported. These episodes were counted to derive the Integral of Individuated Movement (IIM) episodes value. This value indicates how much the subject was moving the index finger independent of the middle finger and vice versa. IIM reflects how much the patient is capable of controlling one finger independent of the other during executing a functional task. The parameters (RaOM and IIM) calculated based on the recorded data were used as the main outcomes of FMED to effectively quantify the amount of movement during the day.

III. FEASIBILITY STUDY

A. Recruitment

Subjects with stroke were recruited from multiple rehabilitation centers in Beirut, Lebanon. Six individuals, with a clinical diagnosis of stroke in the chronic phase (3 males and 3 females, mean age 49.33 ± 8.1, > 6 months post-stroke) participated in the study.

Subjects were included because they had residual upper extremity impairments (Upper extremity Fugl-Meyer [FM] scores, with a range of (45-56)/66; and with mean flexion fingers ROM $\pm$ 1 standard deviation: 73.3 ± 7.4 degrees).

Inclusion criteria was chosen to give a nearly homogenous group of subjects between 40-60 years, with similar representation of both sexes, and approximately same degree of hand function deficit. The participants signed informed consents approved by the Lebanese University, school of health ethical review board.

B. Feasibility Testing Protocol

The first step in the procedure was to meet the subjects to inform them about the study, the device, and train them to use it at home. Patients wore the glove at home for two days. In the first day, they were requested to wear the glove in the impaired hand and use it like they usually do
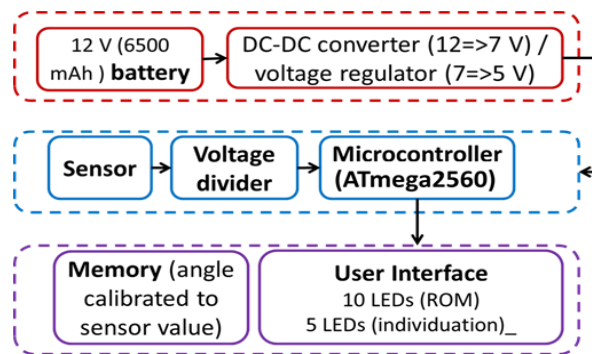

Figure 1: Main components of FMED

TABLE I. USER FEEDBACK QUESTIONNAIRE RESULTS

Question	Average	SD	t-value	p-value
I felt comfortable as the glove was put on	6.33	0.82	7.0	
I did not feel like my fingers were put into any uncomfortable position as the glove was put on	6.33	1.21	4.7	
I felt any restriction to movement with this glove is similar to other gloves I have worn	6.67	0.52	12.6	
I would feel comfortable wearing this glove in public	6.67	0.52	12.6	
I felt comfortable performing the activities in this study	6.50	0.84	7.3	
I feel I can do most of my daily activities (except those involving water) while wearing this glove	6.67	0.52	12.6	
The glove did not feel too tight (it did not make my hands or fingers tingle)	6.83	0.41	17.0	< 0.001
I feel like I can bend my fingers just like I can without wearing the glove	6.83	0.41	17.0	
The glove did not feel too hot or too cold	6.50	1.22	5.0	
I did not feel like my fingers were put into any uncomfortable position as the glove was removed	6.33	1.03	5.5	
I felt comfortable as the glove was removed	6.33	0.82	7.0	
Average	6.55	0.20		

during daily activities, and remove it before sleeping. In the second day morning, they received a call from the study personnel and they were asked to wear the glove and to do specific activities by their impaired hand during the day in addition to their daily routine. The research team did not supervise the patient at home; however, the device recorded the data of movement of the patient on the SD card. The following day, FMED was collected from subjects, each subject filled the user feedback questionnaire, and the data saved on the SD card were collected for offline analysis.

Acceptance of the device and patient's feedback was evaluated based on a user feedback questionnaire [12], and an open-ended discussion, performed after using the device for two days. The participants were supposed to answer a list of 11 question by a scale of 1 to 7. 1 means strongly disagree and 7 means strongly agree, and 4 means neutral. The study personnel were mainly interested to know if the device was comfortable or not, and if it was effective in engaging the subjects in doing more home daily activities. The recorded data were inspected for quality, and movement quality parameters (RaOM and IIM) were calculated in order to inspect if these parameters change in the second day after the study personnel has asked the participants to do extra exercising.

IV. RESULTS AND DISCUSSION

The following section presents the results of the user feedback questionnaire and the recorded data. Table I lists the questionnaire questions and the mean of responses on each question and the results of the t-test performed between the mean of responses of each question and a hypothesized mean of 4 [neutral score]. Results show a significant difference from the neutral score (p<0.001). In the open ended discussion, subjects expressed high

satisfaction and reported that the visual feedback by the LEDs was engaging and motivating to move the impaired hand more than usual. They also expressed their willingness to use FMED at home for a therapeutic intervention because of being passionate to intensify their hand use during daily activities.

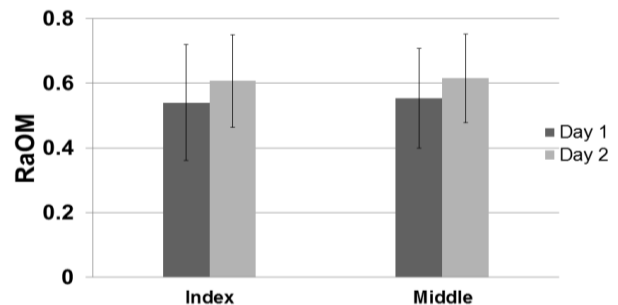Figure 2: Prototype of FMED worn by a volunteer.

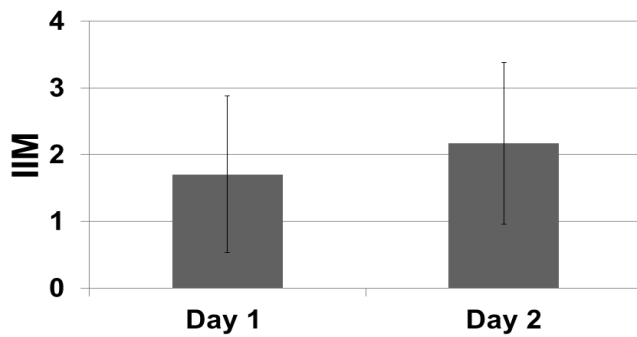Figure 3:RaOM results for both fingers in days 1 and 2.

Figure 4: IIM results in days 1 and 2.

It should be noted here that the activity initially reported on day 1 might not faithfully reflect the regular activity of the participants without using the device; while wearing FMED subjects might be moving more than they usually do knowing that they are being watched. This is known as the Howethorne effect [18]. However, the participants are stroke survivors and they have movement impairments. Thus, the Howethorne effect will not increase the movement score beyond subject's true functional capability although it might increase the amount of his or her movement in comparison to regular days. This brings us back to another argument which says that it is helpful if these individuals with movement impairments felt they are watched so they move more according to their functional capability. In addition, being watched and by getting positive visual feedback of their movement (like the feedback by the LEDs in FMED), they will get better engaged in daily life functional activities, more than they averagely do. This is believed to be helpful in avoiding the learned non-use phenomenon in stroke survivors where the less they use their impaired limb the harder it gets for them to recover their motor skills due to brain remodeling over time[9].

V.   CONCLUSION AND FUTURE WORK

FMED allows clinicians to evaluate the improvement of hand function in the context of home environment. It can be a useful tool to complement the role of standardized outcome measures by assessing the hand use in real life so that clinicians are not limited to the clinical setting. The high rate of acceptance of FMED by the participants in this study and high enthusiasm of patients to using it for therapy, especially due to the presence of visual feedback suggests the need to test the usability of FMED in a home-based rehabilitation therapy intervention especially that it can be produced with a very low cost (~$100). Low cost, user friendly, and low weight, are the main advantages of FMED in comparison to other hand motion tracking gloves that are available in the market in addition to the presence of visual feedback setup which allows FMED to be useful as a therapeutic tool not just as movement recording device. In the future, additional testing will be done to evaluate FMED as a tool to evaluate the use of impaired hand during home-based therapy.

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