Combining Soft Robotics and Brain-Machine Interfaces for Stroke Rehabilitation

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Abstract Stroke is a devastating condition with profound implications for health economics and resources worldwide. Recent works showed that the use of brain-machine interfaces (BMI) could help movement improvements in severely affected chronic stroke patients. This work shows the feasibility and use of a Soft Orthotic Physiotherapy Hand Interactive Aid (SOPHIA) system, able to provide more intense rehabilitation sessions and facilitate the supervision of multiple patients by a single Physiotherapist. The SOPHIA device is controlled by a BMI

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system and has a lightweight design and low cost. Tests with researchers showed that the system presents a reliable and stable control, besides being able to actively open the volunteers' hands.

1 Introduction

Stroke is a global issue affecting people of all ethnicities, genders and ages [1]. Approximately 20 million people per year suffer a stroke worldwide [2, 3], and from the survivors a quarter of them remain severely handicapped and dependent on assistance in daily life [4]. This condition will cause not only economic problems, but also in quality of life and welfare.

Recently, new recovery strategies, e.g., constraint-induced movement therapy (CIMT), or robot-assisted therapy were clinically tested for stroke rehabilitation and have proved to be effective, although restricted in their applications, since they can be used only on stroke patients with residual movement capabilities, which account for 50–70% of the cases [5]. Where these systems cannot be used, there is no accepted and efficient rehabilitation strategy available for patients with chronic stroke and no residual hand movements [6]. Brain Machine Interface (BMI) systems could be a solution for those who suffered a stroke and need to rehabilitate a completely paralyzed limb and a damaged brain at the same time [7].

1.1 Brain-Machine Interfaces (BMI)

A BMI system allows direct translation of electric or metabolic brain activity into control signals of external devices or computers bypassing the peripheral nervous and muscular system [8]. In 2013 Ramos-Murguialday et al. showed for the first time that patients in the experimental group, that received active BMI + physiotherapy during 1 month, recovered motor functions more than patients in the control group, that received sham BMI + physiotherapy [9]. This work was done inside a hospital and with a limited amount of BMI training per day where patients had access to a fixed hand orthosis device.

In order to offer patients an orthosis device where they could be able to run the BMI at home or even in daily life activities, we consulted with physiotherapists, both for design consideration and functionality of the device. The main points raised by these professionals were that the system should leave as much of the palm and fingers exposed as possible to allow interaction with objects, and secondly that the exoskeleton must be unobtrusive and lightweight. Our soft robotics exoskeleton hand would attend these requests.

1.2 Soft Robotics

An initial soft-exoskeleton-based system named the PneuGlove, was developed in 2009 and this device used a combination of a pneumatic pump and servos arrangement to inflate a bladder in each finger, pushing them into extension [10]. We designed and built a soft silicone-based material to allow for a lighter and safer device.

2 Materials and Methods

Five researchers participated in this study.

2.1 BMI Training

The experiment was based on the Graz BCI group [11], where subjects were instructed to think in nothing when the arrow pointed to the left side, or imagine opening the right hand whenever they saw an arrow pointing to the right side on the screen, (Fig. 1). EEG signals were amplified and sent to a laptop that used OpenViBE® to control the device. After the training phase, the subjects were able to send the commands to the SOPHIA device to actively open their right hand on demand.

Fig. 1 BMI training scenario using EEG and the SOPHIA device

2.2 Eelectroencephalography (EEG) Devices

Data were collected using an EEG which is a non-invasive acquisition device. The BMI system was tested with both ActiCAP (Brain Products) with 16 channels over the motor area, and with an Epoch+ (Emotiv) headset. The EEG signals were processed in OpenViBE® and sent from the BMI system to the Arduino (Mega 2560) via a C++ communication protocol. All sensor data including the piezo-resistive flex sensors (Sparkfun; SEN-08606), pressure sensors (Mouser; 785-HSCDANN1.6BASA5), diaphragm pumps and solenoid valves were saved for data analysis.

2.3 Data Analysis

Each researcher run 4 sessions, each of them with 160 random trials. Data was band-pass filtered between 8-30 Hz and then submitted to a previously calculated common spatial pattern (CSP) filter with six dimensions; data was than cue-based epoched, squared, averaged, long-transformed, and finally applied to a two classes linear discriminant analysis (LDA) classifier. Data processing was performed with OpenVibe® and custom Matlab® routines.

3 Results

Every time the BMI system detected a right hand opening imagination the glove was inflated until a flex sensor stop it. During the inflation, fingers were actively extended.

One-sample t-test showed that all researchers were able to control the SOPHIA device using Brain Products electrodes over 70% ($M = 83.1$, $SD = 9.00$), $t(4) = 3.25$, $p = 0.031$. The range of performance in percent was between 73.6 and 95.4. All researchers reported that they felt controlling the device mostly of the time and the diaphragm pumps could open their hand. Performance using Epoch+ decreased significantly.

4 Discussion

Initial results showed that the SOPHIA device, controlled by BMI, has a potential to be used for stroke rehabilitation and help improving recovery both in hospital and at home. Despite of that the first prototype might lacks power to open the hands of patients with strong spasticity. Further development needs to be done in order to have this product available for patients.

The control using Brain Products electrodes were higher than using Epoch+, but we must say that we used the standard electrodes position for Epoch+, and this needs to be rearranged in order to have the electrodes over the motor area to improve control performance.

Previous studies reported that BMI techniques showed positive results in stroke survivors improving motor function in a completely paralyzed limb meanwhile the damaged brain was trained at the same time. The SOPHIA device could help these improvements offering the patients a more intensive training rehabilitation program at their home.

5 Conclusion

Our preliminary outcomes reassure the feasibility of building an inexpensive, easy to wear soft robotics device suitable for home or physiotherapy clinical care. Its lightweight and soft anatomical design facilitate real grasp movements while monitoring finger extension and duration of practice. This contributes to a more intensive training routine that could lead to faster and higher motor improvements, decreasing patient's impairments and helping their functional recovery.

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