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MoA1	Auditorium Jorge Caron	Monday (November 20) 10:00 - 11:40
Lower Limb Exoskeletons		
Chair: Adriano A. G. Siqueira (EESC/USP)		
MoA1.1 - 55 **10:00 – 10:20**	**Precise Elbow Angle Measurement for Exoskeletons Applications: Comparison between Optical Fiber and IMU-based sensors** Sophia Otálora (UFES), Marcelo E. V. Segatto (UFES), Maxwell E. Monteiro (IFES), Carlos Cifuentes (UWE Bristol), Camilo Arturo Rodriguez Diaz (UFES)	
MoA1.2 - 31 **10:20 – 10:40**	**Development and Design of an Innovative Smart Exoskeleton-Crutch System** Victor Ferman (UNICAMP), Felipe Augusto Oliveira Mota (UNICAMP), César Bastos da Silva (UNICAMP), Eric Rohmer (UNICAMP)	
MoA1.3 - 40 **10:40 – 11:00**	**Optimizing Motor Imagery Training for Lower-Limb Exoskeleton Control Through BCI** Laura Ferrero Montes (UMH), Paula Soriano-Segura (UMH), Julian Jacobo Navarro Aguilar (ITESM), Oscar Jones (UH-USA), Mario Ortiz (UMH), Eduardo Iáñez (UMH), Jose Maria Azorin Poveda (UMH), José Contreras-Vidal (UH-USA)	
MoA1.4 - 41 **11:00 – 11:20**	**Protocol for Evaluating Error Related Potentials in a Lower-Limb Exoskeleton Commanded by a Brain-Machine Interface** Paula Soriano-Segura (UMH), Laura Ferrero Montes (UMH), Mario Ortiz (UMH), Eduardo Iáñez (UMH), Jose Maria Azorin Poveda (UMH)	
MoA1.5 - 61 **11:20 – 11:40**	**Uso Combinado do Lokomat e Imagética Motora com Neurofeedback para Modulação do Ritmo Sensório-Motor após a Lesão Medular Espinal: Um Relato de Caso** Ericka R. S. Serafini (IIN-ELS), Denis Delisle-Rodriguez (IIN-ELS), Fabíola R. Campos (IIN-ELS), André Felipe de Azevedo Dantas (IIN-ELS) , Aleandra S. Castro (UFRN), Arthur Monjardim (UFRN), Marana A. Silveira (UFRN), Juliana C. Silva (UFRN), Caroline C. do Espírito Santo (IIN-ELS)	

OPTIMIZING MOTOR IMAGERY TRAINING FOR LOWER-LIMB EXOSKELETON CONTROL THROUGH BCI

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Abstract: Motor imagery (MI) has been commonly used as a control paradigm in brain-computer interfaces (BCI). MI allows users to execute movements in an output device by simply thinking about it, which has potential benefits for promoting neuroplasticity. However, MI has high heterogeneity among users and it can be challenging for some of them, which it is difficult to monitor. To address this issue, a standardized training protocol was developed for performing MI in a BCI to control a robotic exoskeleton. Additionally, the Movement Imagery Questionnaire-3 (MIQ-3) was utilized to evaluate each participant's MI ability. The aim of the protocol was to reduce BCI illiteracy and improve the homogeneity of MI performance among users.

Key words: brain-computer interface; motor imagery; robotic exoskeleton; EEG.

1. Introduction

Motor imagery (MI) is the cognitive process of generating mental representations of physical movements without any overt movement execution (Butler & Page, 2006). MI has been primarily utilized as a control paradigm in brain-computer interfaces (BCI). BCIs act as intermediaries between the brain and external devices. MI enables users to execute movements in an output device simply by thinking about it.

Exogenous paradigms, which rely on external stimuli, are also used in BCI. For instance, lights at different frequencies or particular sounds that can evoke certain brain responses (Kwak et al., 2015). In contrast, MI is a spontaneous paradigm as users can choose when to perform it. The main advantage of MI is that it is more intuitive, user-driven, and can enhance mechanisms of neuroplasticity. This could promote recovery, especially when motion feedback is incorporated (Gharabaghi, 2016). Nevertheless, MI has high heterogeneity among users as it can be performed in different ways, and it is not feasible to monitor. Additionally, some people may find it more challenging or incapable of using this task to control a BCI, which is known as BCI illiteracy (Leeuwis et al., 2021).

There are three main ways to perform MI: visual external motor imagery, visual internal motor imagery, and kinesthetic motor imagery (Yang et al., 2021). Visual external motor imagery involves mentally simulating motor tasks from an external perspective, as if observing oneself from a third-person viewpoint. Visual internal motor imagery, on the other hand, entails mentally rehearsing motor actions from a first-person perspective, immersing oneself in the mental visualization of movements, sensations, and proprioceptive feedback. Kinesthetic motor imagery, also known as kinesthetic motor simulation, emphasizes the internal sensations and feelings associated with movement, such as muscle contractions, joint positions, and proprioception. While subjects generally find it easier to perform visual motor imagery, kinesthetic imagery activates the motor cortex more than visual imagery, modulating corticomotor excitability and promoting rehabilitation to a great extent. here are three main ways to perform Motor Imagery (MI): visual external motor imagery, visual internal motor imagery, and kinesthetic motor imagery (Yang et al., 2021).

The objective of this research is to design a training protocol to perform kinesthetic MI in a more homogeneous way and standardize the training with the BCI. Users will practice the task prior to using the BCI and during the usage, and a standardized questionnaire will be utilized to extend the practice and measure the ability of each subject to perform each type of MI.

2. Development

2.1 Equipment

Brain activity was recorded via electroencephalography (EEG) using a bundle of 32 wet electrodes placed over actiCAP (Brain Products GmbH, Germany), with electrode placement following the international 10-10 system. Electrooculography was recorded by placing 4 electrodes next to the eyes. The ear lobes served as the reference and ground electrode. The recorded data was wirelessly transmitted using a Move transmitter (Brain Products GmbH, Germany), then amplified by a brainAmp unit and recorded in a laptop.

The subject was outfitted with the Rex exoskeleton (Rex Bionics, New Zealand), a self-standing robotic prosthesis that enables full standing and walking without any vertical inclination or crutches. The exoskeleton tightly attaches to the subject's limbs with multiple straps, ensuring that lower limb movements are exclusively dictated by the BCI, preventing any extraneous movements by the subject. Figure 1 shows all the equipment.

2.2 Experimental sessions

In accordance with Figure 2, each subject participated in 5 daily sessions, where training was implemented differently in each one. In the first session, since participants had no prior experience with BCI, they did not use it. The researchers briefed the participants on the research goal, the concept of motor imagery and provided instructions on the mental tasks to be performed. Subsequently, the participants used the exoskeleton to become familiar with it and concentrate on the somesthetic sensations that would evoke kinesthetic MI. Finally, participants were given a MI questionnaire to complete at home.

During the second and third sessions, participants were given the same mental task instructions as the previous session and practiced MI while being static. Then, they spent 15 minutes familiarizing themselves with the exoskeleton and focusing on the sensations evoked by the movement. Finally, they used the BCI under open-loop control, whereby the commands sent to the exoskeleton were not dependent on the user's thoughts, but on pre-established sequences. In this way, data was collected under different conditions.

The fourth and fifth sessions were the same as the second and third, with the distinction that after open-loop control, participants began to operate the exoskeleton with their thoughts (closed-loop control).

2.3 Instructions

In this study, participants were instructed to alternate between periods of kinesthetic motor imagery and being in an idle state, as a means of controlling the start and stop of walking forward with the Rex exoskeleton. The explicit instructions provided to participants for performing motor imagery and being in an idle state are detailed in Table I.

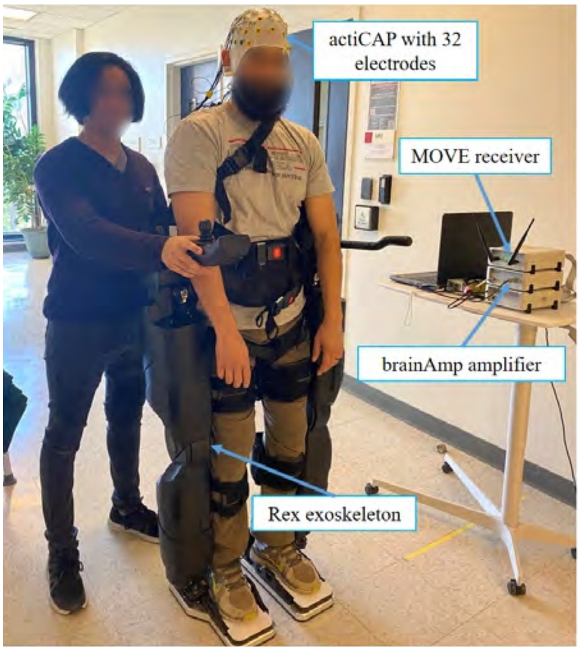

Figure 1. Equipment used in the protocol.

2.4 Questionnaire

To evaluate participants' ability to engage in motor imagery, the Movement Imagery Questionnaire-3 (MIQ-3) was employed in both English (Williams et al., 2012) and Spanish languages (Trapero-Asenjo et al., 2021). This self-reported questionnaire requires participants to imagine themselves performing four distinct movements, including arm abduction and adduction, standing hip flexion, knee lift, and jumping, using a range of different imagery modalities, including external visual imagery, internal visual imagery, and kinesthetic imagery. Participants are then asked to rate the perceived difficulty of each item on a scale, providing researchers with a measure of the efficacy of each modality.

Table I. Instructions given to participants to perform each mental task.

Kinesthetic motor imagery	"Keep your eyes open." "Minimize visualization and focus on the body sensations evoked by the movement of walking." "For example, pay attention to the sensations of movements in joints, muscle contraction and coordination of different body parts, pressure of the foot sole."
Idle state	"Keep your eyes open." "Focus on the breathing." "If any though comes to your mind, do not focus on it."

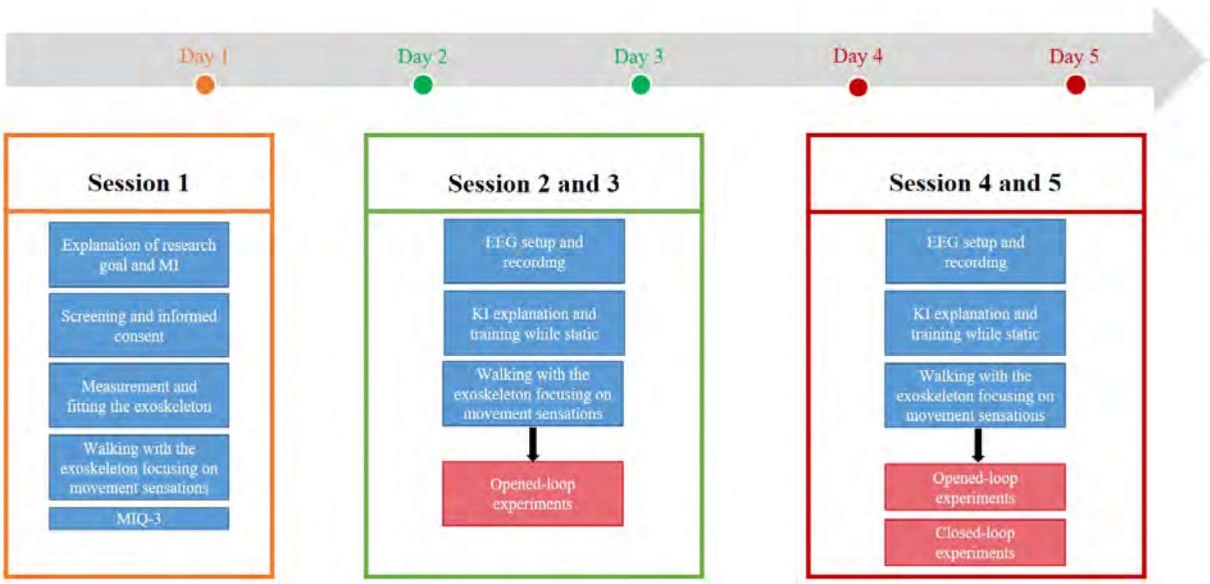

Figure 2. Schema of the experimental sessions. Subjects participated in 5 daily sessions. Blue boxes represent preparatory steps and training activities, while red boxes indicate the experimental phase where data was collected to control a robotic exoskeleton. As all participants were unfamiliar with brain-computer interfaces (BCI), the first session focused on familiarizing them with the mental imagery concept, concretely with kinesthetic imagery (KI), practicing the associated motor tasks, and adjusting to the robotic exoskeleton. Subsequent sessions involved data collection using the same procedures.

3. Conclusion

In conclusion, the present research introduces a protocol for the training of MI prior to its application in a BCI used for controlling a robotic exoskeleton. The training program is designed to be extended over the course of the usage of the BCI, representing an initial step towards the standardization of MI protocols.

One important component of this protocol is the use of the MIQ-3 as a tool to evaluate the ability of each individual to perform MI. By incorporating the MIQ-3 into the protocol, researchers are able to gain a more comprehensive understanding of the efficacy of the MI.

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