Capturing Shoulder Exoskeleton-based Neural Adaptations during Upper Extremity Tasks

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Passive shoulder exoskeletons have shown to lower biomechanical demand for upper extremity manual work (Gillette & Stephenson, 2019). Current studies that evaluate passive shoulder exoskeletons primarily focus on its ability to lower the load on the shoulder musculature (Gillette & Stephenson, 2019; Van Engelhoven et al., 2018). However, the effectiveness of such wearable solutions may need comprehensive evaluations of both the physical and cognitive interplay between the wearer and the exoskeleton for specific tasks. For now, the main criteria to evaluate exoskeleton has been the amount of physical workload it reduces. However, if physical load is significantly reduced, but exoskeleton requires extra mental workload, then the effectiveness of it should be rediscussed and reconsidered. Specifically, one consideration for cognitive fit may be the neurocognitive requirements of motor adaptation associated with the use of shoulder exoskeleton, that may potentially differ between different tasks and/or exoskeleton designs. Thus, the evaluation of the motor adaptation with exoskeleton uses and associated neural efficiency is critical to understand and assess human-exoskeleton interactions. To fill this knowledge gap, this study aims to capture neural adaptation to upper extremity tasks using a shoulder exoskeletons over the course of three days.

A between-subject design was employed, wherein, participants (assigned randomly to a non-exoskeleton or exoskeleton group) performed overhead reaching and pointing tasks (shown in Figure 1b) holding a 1.36 kg drill in their right hand over three consecutive days. Participants performed 2 reaching and pointing tasks: task 1 was performed in the absence of additional mental workload; task 2 was performed with additional mental workload levied by a supplementary mental math task. The tasks were modified based on the design made by Maurice et al. (2020) and Kim et al. (2018) and required participants to press two electronic buttons back and forth for twelve repetitions with their feet in a fixed position and shoulder and arm flexed at 90° (Figure 1b). Participants were asked to perform 5 trials per task; each trial required the twelve repetitions. During the experiment, functional near-infrared spectroscopy (fNIRS) was used to collect hemodynamic activity of the motor and prefrontal regions of the brain. Electromyography (EMG) was used to measure muscle activation in shoulder and lower back muscles. Additionally, subjective questionnaires: rate of perceived exertion (RPE) and NASA Task-Load Index (NASA-TLX), and performance (calculated as time taken to complete each trial) of the task were recorded. As shown in Figure 1c, the probe design of fNIRS has 41 channels distributed over 10 regions of interest (ROIs): prefrontal cortex (R/L PFC), primary motor cortex (R/L M1), premotor & supplemental motor area (SMA; R/L PM), somatosensory cortex (R/L S1), and superior parietal lobule (SPL). The experiment protocol is shown in Figure 1a. A training session to familiarize participants with the tasks was conducted before starting the experiment.

So far, we have collected data on 19 participants (8 females and 11 males) and we are planning to recruit 24 participants, balanced by gender, in total. Repeated measures Analyses of Variance (ANOVAs) of day (Day 1, Day 2, Day 3) × sex (males, females) × group (exoskeleton, non-exoskeleton) will be performed on the rmsEMG of the shoulder, upper arm, and lower back muscles, peak activation and on the 10 ROIs, subjective questionnaires, and performance data with FDR corrections at $q=0.05$ (Benjamini & Hochberg, 1995).

The preliminary trends of two male participants (one in the non-exoskeleton group and the other one in the exoskeleton group) is shown in Figure 2. It presents participants' performance of the two tasks over three days along with their activation maps. Preliminary findings show that time taken to complete was lower when equipping exoskeleton. Activation was higher for the person who equipped with the exoskeleton for both task 1 and task 2. A complete analysis will be conducted after finishing the data collection to test the following hypotheses: 1. Exoskeleton group will exhibit reduced EMG activity in the shoulder muscles; and 2. The neural activation profiles will be group- and task-dependent.

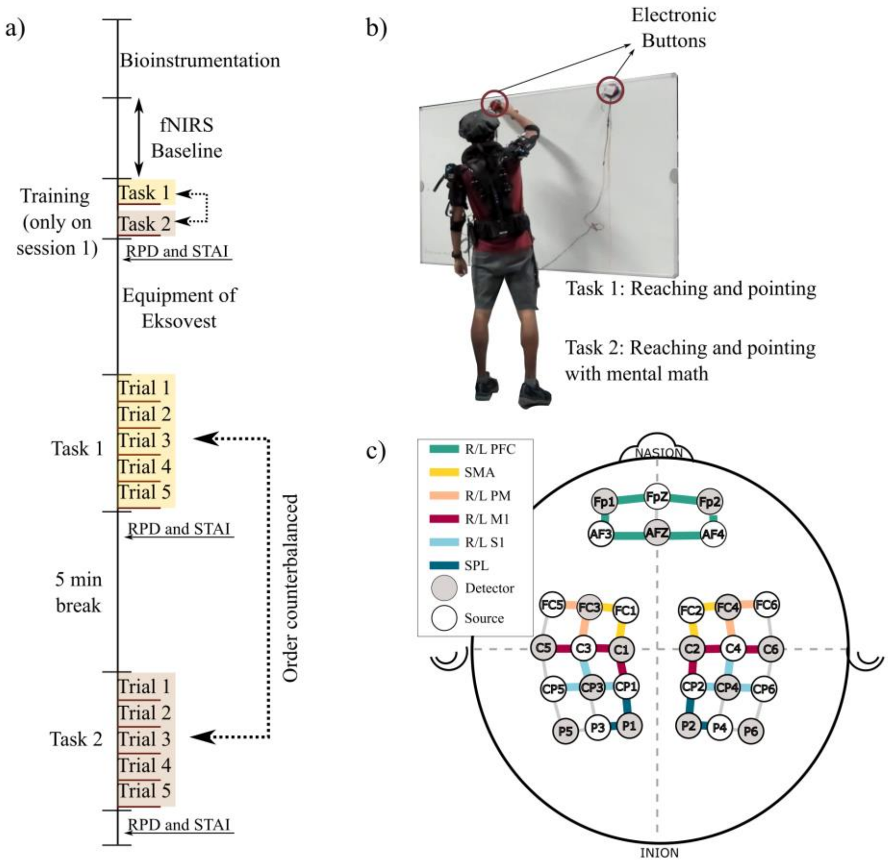

Figure 1: Experimental protocol of the study (a), after completing each trial, rate of perceived exertion (RPE) and NASA TLX were asked.; Posture of one participant conducting the task (b); fNIRS probe design (c).

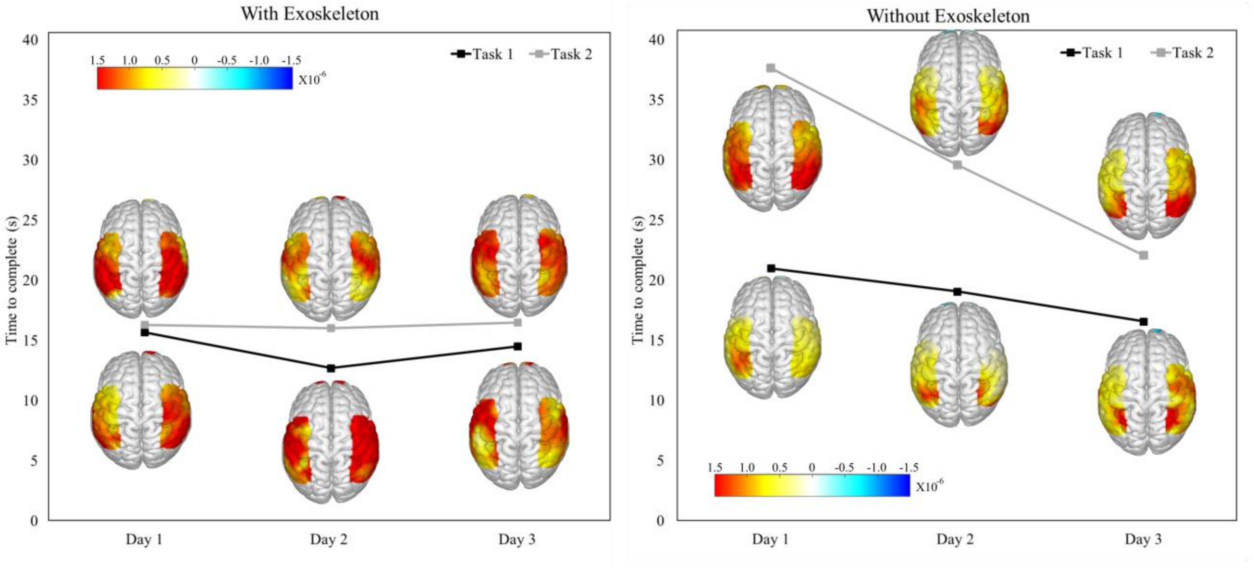

Figure 2: Changes in performance (line graph) and associated neural activation patterns over the three days for task 1 (physical only) and task 2 (physical with cognitive dual task) in the control and exoskeleton group.

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