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### ► To cite this version:

Clément Trotobas, Fernanda Márcia Rodrigues Martins Ferreira, João Paulo Fernandes Bonfim, Maria Rosália de Faria Moraes, Adriana Maria Valladão Novais Van Petten, et al.. A Feasibility Study of a hybrid approach using FES and a Mechanical Orthosis to Restore Hand Movements in Individuals with Tetraplegia. ICNR 2024 - International Conference on NeuroRehabilitation, Nov 2024, La Granja, Spain. hal-04700894

**HAL Id: hal-04700894**

**<https://hal.science/hal-04700894v1>**

Submitted on 19 Sep 2024

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# A Feasibility Study of a hybrid approach Using FES and a Mechanical Orthosis to Restore Hand Movements in Individuals with Tetraplegia

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**Abstract**— This study explores a novel method combining functional electrical stimulation (FES) with a motorized orthosis to aid prehension in individuals with tetraplegia. Surface FES activates muscles for moving fingers, thumb, and wrist joints, while electric motors lock the joints in desired positions. The goal is to reduce muscle fatigue compared to FES alone and enable prolonged grasping. The feasibility and acceptability of this hybrid orthosis were tested on five participants with upper-limb paralysis due to spinal cord injury. Assessments included grip quality on three different objects for 30 seconds, perceived effort using the Borg RPE scale, pain using the visual analog scale (VAS), and acceptability using the QUEST and SUS scales. Preliminary results indicate that the hybrid orthosis could add value compared to FES alone, with functionality scores equal to or better than those achieved with FES alone, and successful object grasping for 30 seconds without muscular fatigue impacting grip quality.

## I. INTRODUCTION

FUNCTIONAL electrical stimulation (FES) can be utilized to activate muscles, enabling grasping tasks in individuals with upper limb paralysis [1]. The early muscle fatigue caused by FES, compared to voluntary muscle activation, reduces the efficiency and duration of movements [2], [3]. Recently, hybrid orthoses have been developed that combine FES with active mechanical orthoses or exoskeletons [4], [5]. Most published studies focus on shoulder and elbow movements [6], [7]. We propose a solution where wrist and finger movements are induced by electrical stimulation of the forearm muscles. The induced actions are guided by a mechanical structure, and once the final grasping posture is achieved, the stimulation stops, and the joints are passively locked by the mechanical orthosis. By limiting the contribution of the motors to joint locking, it is possible to reduce their power requirements, thereby minimizing their size and weight.

The objective of this preliminary study was to evaluate both

qualitatively and quantitatively how effective the prototype hybrid orthosis was in reducing muscular fatigue during grasping compared to using FES alone among participants with upper limb motor impairment resulting from spinal cord injury. Additionally, it aimed to assess improvements in the quality of grasping.

## II. METHODS

A motorized mechanical cable-driven orthosis for the right wrist and fingers (Exo Hand, Aufratech, France) was developed. It includes adjustable attachments for customization to different arm and finger sizes. A first motor unit tightens or loosens simultaneously the five finger cables, while a second motor unit adjusts the wrist cable. The orthosis is designed to be non-back drivable to lock joints. An electrical stimulator (Phenix Neo©, Montpellier, France), consisting of a central controller linked to a computer and two wireless stimulation units (PODs) was used. Three pairs of surface electrodes were employed: one for extending the wrist and fingers, another for flexing the fingers, and a third for flexing the thumb. When the joints are mechanically locked, the electrical stimulation is turned off, to prevent fatigue.

A controller manages the 3 electrical stimulation channels and the 2 DC motors through a multi-threaded Graphical User Interface developed in Python. It communicates with the motor control board (Adafruit Feather nrf52840 control board) and the stimulator controller via serial COM. The controller operates as a state machine (Figure 1), allowing independent or simultaneous control of motors and stimulators based on selected settings. A push button, activated by the contralateral hand, triggers state changes among NEUTRAL, OPEN (maximum finger extension), and CLOSE (finger flexion) states. The sequence always starts from NEUTRAL, progressing through OPEN and CLOSE states, adjusting hand posture for grasping objects. Motor

Research was conducted within the context of Inria - UFMG Associate Team. This work was carried out with the support of the Coordination for the Improvement of Higher Education Personnel - Brazil (CAPES) through the Academic Excellence Program (PROEX).

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actions cease based on speed thresholds, ensuring effective object handling and user comfort.

This study was approved by the Institutional Ethics Committee of the Federal University of Minas Gerais with CAEE registration 53757521.3.0000.5149 and conducted under the Declaration of Helsinki.

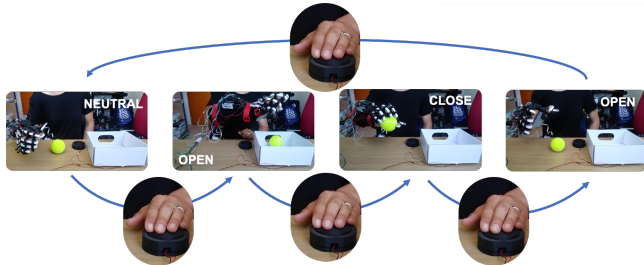


Fig. 1. The controller of the hybrid orthosis controls FES and electric motors contributions, it operates as a state machine: a push button triggers state changes among NEUTRAL, OPEN and CLOSE.

Five adult participants with spinal cord injuries (levels C4-C7) were recruited. Participants had no active finger flexion/extension.

The protocol included 3 sessions using 3 objects: a ball, a fork adapted with a thickener, and a half-filled 50cl water bottle. Objects were used in a random order. Each session involved the participant sitting in front of an adjustable table with the device attached to their right upper limb.

**Sessions 1 and 3:** Only FES was used. Stimulation was set at 40Hz and 500 $\mu$ s pulse duration, with individual current amplitude adjustments. Participants' ability to hold the 3 objects for 30 seconds was assessed, with the arm positioned comfortably on a pillow. The experimenter placed the object in the hand. The sequence was repeated 3 times per object, with 30-second rests between repetitions and 2-minute rests between different objects. Success rate, manipulation time, perceived effort (Borg RPE scale), and pain presence (Visual Analog Scale) were evaluated.

**Session 2:** The hybrid orthosis was used, with the same evaluation and training as in the other sessions. Additional assessments included acceptability and usability using the Quebec User Evaluation of Satisfaction Technology with Assistive Technology (QUEST) and System Usability Scale (SUS) scales. The orthosis was donned and doffed by the experimenter. For QUEST the average result was 4.1 $\pm$ 0.43, and SUS was 76 $\pm$ 13.38.

When possible, participants used a control button with their contralateral arm to activate device state changes.

## II. RESULTS

The use of the hybrid orthosis generally improved the quality of object grasping compared to electrical stimulation alone. This objective was achieved, as the electrical stimulation was turned off, while the powered part of the orthosis maintained the hand's positioning during the task. The hybrid device showed no evidence of muscle fatigue (finger posture relaxation) and allowed for longer grasping durations. The

approach was feasible and well-received by participants, although design improvements are needed. The BORG Rating of Perceived Exertion scale indicated that the approach was well tolerated. The Visual Analog Scale showed that the FES and orthosis did not cause pain or discomfort, except for participant P3. Some temporary redness at orthosis pressure points was observed, disappearing within 30 minutes. The SUS scale scores showed that two participants rated the device highly, while three had respectable scores but noted issues with ease of use and device bulkiness. Participants expressed confidence in the device and believed that users would quickly learn to use it once it reached technological maturity. The prototype was not in a wearable version, and components were not fully integrated, making autonomous use difficult. Future versions will integrate all components, including battery-powered motors and embedded controllers.

## III. CONCLUSION

The study proposed a novel hybrid orthosis integrating electrical stimulation for finger, thumb, and wrist muscles with a mechanical framework using low-power motors. This design aimed to synchronize FES-induced movements with passive motor properties, enabling effective object grasping and stable grip over prolonged periods. The prototype was tested on five individuals with tetraplegia, showing better performance than FES alone. Further studies with larger participant numbers are needed for statistical analysis. The feasibility test only included one session with the orthosis, which limited the observation of external interfering factors and is a limitation of the study. In future work, long-term results can also be evaluated.

## ACKNOWLEDGMENT

We warmly thank all the participants.

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