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***Abstract*— The development of brain/neural-controlled exoskeletons allow for restoration of movements in paralysis. By translating brain activity associated with the intention to move, such systems enabled, e.g., quadriplegic patients with complete finger paralysis to eat and drink in an outside restaurant. However, noninvasive means to record brain activity often lack sufficient signal quality for reliable and safe operation, particularly in noisy, uncontrolled environments or presence of muscle artifacts due to whole body movements. Thus, hybrid control paradigms were developed that merge different biosignals to increase reliability of exoskeleton control. Here, we introduce such control paradigm for restoration of gait using a personalized exoskeleton based on electroencephalographic and electrooculographic (EEG/EOG) signals. While exoskeleton movements were initiated by event-related desynchronization (ERD) of sensorimotor rhythms (SMR) associated with the intention to walk, the exoskeleton was stopped by a specific EOG signal. Using such paradigm does not only provide intuitive control, but may also trigger neural recovery when used repeatedly over a longer period of time. Further validation of this approach in a larger clinical study on gait assistance and rehabilitation will be needed.**

I. Introduction

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The last years yielded the development of brain-machine interfaces (BMI) translating electric, magnetic or metabolic brain activity into control commands of external devices, such as robots, prostheses or exoskeletons. While implantation of microelectrodes or electrode grids was shown to allow for high-dimensional control of such devices, the required surgery involves the risk of bleedings and infections. Thus, noninvasive BMIs that use signals recorded from the surface of the skull provide an attractive alternative, but are limited in the number of commands decodable per second or minute. This limitation does not only relate to the information density of the signal, but also to the presence of signal artifacts from various sources impeding correct classifications. Besides non-stationarity of EEG signals, particularly muscle artifacts can substantially lower correct classification rates of noninvasive BMIs. This critically limits the usability of such systems in everyday life environments where assistance has to be reliable and safe. To overcome this problem, a novel brain/neural control paradigm that combines EEG and EOG signals was implemented. It was shown that this approach is feasible and safe to operate a hand exoskeleton [1], a whole-arm exoskeleton [2] and also bilateral hand exoskeletons [3], e.g., to perform bimanual tasks. However, implementation for lower-limb exoskeleton control was not demonstrated yet.

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II. Methods

EEG/EOG signals were recorded with an active wet electrode system (actiCAP®) attached to a wireless amplification unit (LiveAmp®, Brain Products GmbH, Gilching, Germany). Signals were assessed from nine scalp electrodes in proximity to the sensorimotor areas (F3, F4, T3, T4, C3, C4, P3, P4, and Cz) across two healthy volunteers. Bipolar EOG was recorded from electrodes at the left and right outer canthus. A reference electrode was placed at FCz and ground electrode at FPz. All bio-signals were sampled at 1 kHz as well as high-pass and notch filtered at 0.1 and 50 Hz to remove baseline drifts and line noise. EOG signals were additionally bandpass filtered at 10-100 Hz. For online processing, a customized version of the BCI2000 platform was used [4]. Before online control, the system was calibrated by setting an individualized SMR-ERD detection threshold. SMR-ERD was calculated based on a 3-Hz frequency bin centered around 11 Hz and translated into a start signal for the device. Similarly, an individual EOG detection threshold was set based on maximal horizonal oculoversions (HOV) used to stop the device.

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III. Results

After calibration, both participants were able to control the lower-limb exoskeleton, and reliable initiated and stopped the device using SMR-ERD and HOV. Both participants rated the control paradigm as intuitive and reliable.

IV. Conclusion

Hybrid EEG/EOG control is a promising approach to operate lower-limb exoskeletons to restore gait in paralysis. Larger clinical studies are needed to evaluate the value of this approach across different patient populations.

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