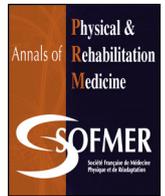




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Letter to the editor

Toward a hybrid brain-machine interface for palliating motor handicap with Duchenne muscular dystrophy: A case report



Dear Editor,

Given that the life expectancy of patients with Duchenne muscular dystrophy (DMD) has increased in recent years, motor handicap is experienced for longer and can also be more severe than in the past. Technical aids have been developed to enable individuals with DMD to interact with an application used in their daily life (an electrical wheelchair, a web browser, a video game, etc.). Indeed, with the approaches reported in Cincotti et al. [1], individuals with DMD can control these applications thanks to a variety of technologies including standard devices (computer mouse, joystick, eye tracker, and voice recognition) and a novel device such as a brain-machine interface (BMI). These devices are chosen as a function of the patient's residual muscular activity and therefore must be replaced as the disease progresses. To avoid changing the patient's control paradigms, it would make more sense to offer a hybrid BMI (hBMI) that could adapt itself to the patient's level of motor handicap by using several signals, including at least one measurement of brain activity (for a review on hBMIs, see [2]).

We have started to develop an hBMI specifically for patients with DMD so that the patient can control several different applications with a single interaction technique based on online, real-time processing of electroencephalography (EEG), surface electromyography (EMG), and joystick signals. Then signal processing detects hand movement (either real or imagined) at different levels in the motor command chain. Two joysticks are used as long as the individual is capable of activating them. Then when disease progression leads to reduced motricity, the hBMI will take account of surface EMG signals and then only EEG signals to detect the same movements or the same movement intentions. Hence, individuals will continue to use the same interaction technique even when their motricity deteriorates. This configuration will avoid having to switch to the use of a single joystick, which requires very accurate hand control. The prototype hBMI we present here analyses rough movements of both hands separately or simultaneously.

As a case study, we report the first results of our prototype hBMI used by 2 individuals with DMD during a virtual kart-driving task. The primary objective of the present study was to assess the relevance of the interaction technique (described below) for controlling the kart by using online-processed surface EMG signals. Although the reliability of surface EMG processing and the efficacy of the interaction technique had already been confirmed in healthy individuals [3], the technology had not previously been assessed in people with DMD. In the present pilot study, surface EMG was preferred over other sensors because 1) joystick use induced too

much fatigue and 2) using EEG would have required a lengthy learning period. Indeed, the final version of our hBMI will be designed to select the most reliable signal as a function of the individual's motricity and to switch smoothly from one signal to another as the disease progresses or the level of fatigue changes. Although EEG signals were not processed online during this experiment, they were recorded to allow for subsequent offline analysis.

The interaction technique incorporated in our hBMI had been designed to enable the control of various applications. The user controls the trajectory of a moving object – either real or virtual – by using 3 independent commands, that is, real or intended movement of the right hand, left hand or both hands together. Right- and left-hand movements result in left rotation and right rotation of the object, respectively, whereas the simultaneous movement of both hands moves the object forward. To help the user master the hBMI, we have developed several game-like applications: driving a vehicle in open and constrained environments, exploring a maze, and controlling a mouse-like cursor [4].

We studied 2 males with severe DMD (aged 20 and 28 years). Both are confined to a wheelchair but have residual motricity in their hands. This proof-of-concept study was made possible by collaboration between researchers from the CRISAL laboratory, the Physical Medicine and Rehabilitation Unit at Lille University Medical Center, and the Centre Hélène Borel (all located in Lille, France). With the use of portable, fully autonomous equipment, the experiments were carried out directly at the individuals' place of residence over about 90 min.

The upper left panel of Fig. 1 shows a person with DMD sitting in front of a computer screen that displays a virtual kart driving task. He is wearing an EEG cap (equipped with 12 active electrodes) placed on the scalp over the primary motor cortex at positions that allowed us to record signals that varied when the patient moved his hands. The upper right panel of Fig. 1 shows 2 surface EMG electrodes specifically placed by a clinician on each hand, depending on the patient's residual motricity. A gUSBamp bioamplifier (gTec, Graz, Austria) was used to amplify and sample EEG and surface EMG signals. It took about 20 min to set up the EMG/EEG electrodes and check the signal quality. The data were recorded and processed online by using OpenVIBE software (INRIA Rennes, France) [5]. Typical surface EMG signals (Fig. 1, lower left panel) clearly showed bursts corresponding to hand movements.

The task consisted of completing 2 laps of a circuit with the kart shown in the lower right panel of Fig. 1, by moving the left or right hand (depending on the intended trajectory). A time constraint (materialized by a “traffic light” graphic) obliged patients to control the kart by spacing out short-duration movements over time, which therefore induced less fatigue. When the traffic light was green, the user could send a command by moving his hands. After the command had been recognized by the system, the traffic light turned immediately red for a fixed resting time (set to 4 sec

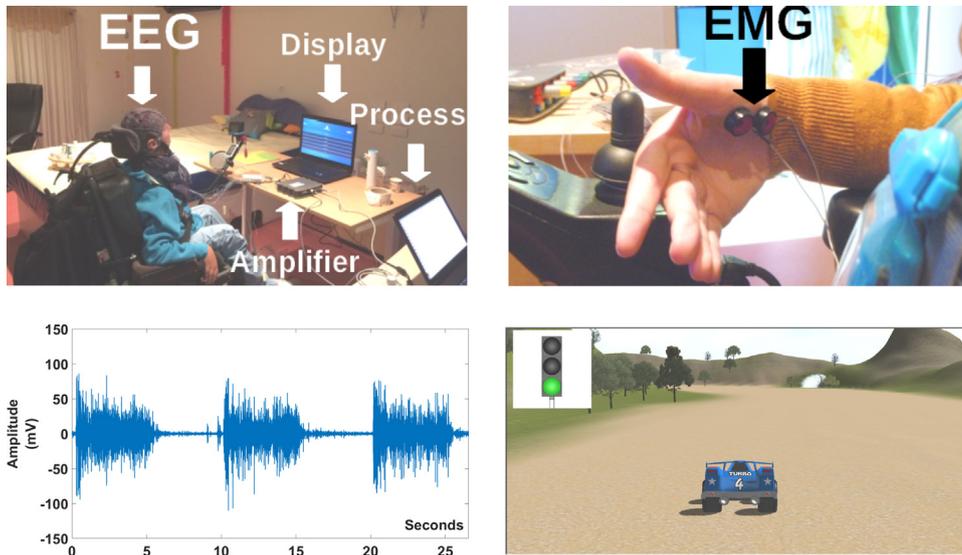


Fig. 1. Upper left: a person with Duchenne muscular dystrophy (DMD) sitting in front of a computer screen that displays a virtual kart driving task. Upper right: 2 surface electromyography (EMG) electrodes placed by a clinician on each hand. Lower left: typical surface EMG signal bursts corresponding to hand movements. Lower right: task consisting of completing 2 laps of a circuit with the kart and showing a traffic light (green, the user could send a command by moving his hands, then red for a fixed resting time after the command had been recognized by the system). EEG, electroencephalography.

here), during which the user could not send another command. To make it easier to control the kart, with short, spaced-out movements, we modified its kinematics by applying a dynamic transfer function for motion inertia [6]. Each lap time (in seconds) was used as a performance metric and was compared with those for 10 healthy individuals performing the same task over 2 sessions. The 2 individuals with DMD also performed 2 sessions.

Fig. 2 shows the mean lap times for each session performed by the healthy individuals and each DMD individual. Although we did not statistically analyse these data, the DMD and healthy participants seemed to have similar lap times. Consideration of these results and an informal debriefing with the participants suggested that the interaction technique integrated into our hBMI was relevant for people with DMD: a video game can be controlled by processing online surface EMG signals. Moreover, we observed a learning effect in both the DMD and healthy individuals, expecting performance improvement with training.

As mentioned above, the DMD individuals' EEG signals were not processed online but were recorded for offline processing. The usual approach for detecting actual or intended movements within EEG signals in motor-imagery-based BMIs consists of detecting event-related synchronizations or desynchronizations of rhythms in the μ and β bands [7]. Detecting these brain patterns will allow for detecting hand movements when surface EMG signals are no longer reliable because of a deterioration in motricity. For example, the curves in Fig. 3 show the average power levels of the EEG signals recorded at electrode C4 for DMD individual 2 (after band-pass filtering in the 12–16 Hz of the low β band) under 2 situations: when moving both hands simultaneously (red curves) and all other conditions (blue curves). A marked resynchronization of the β rhythm after movement offset (1 sec) is clearly visible.

To confirm the conclusive results of this pilot study, we intend to study the same kart-driving task in a larger number of individuals with DMD. Furthermore, to assess the interaction

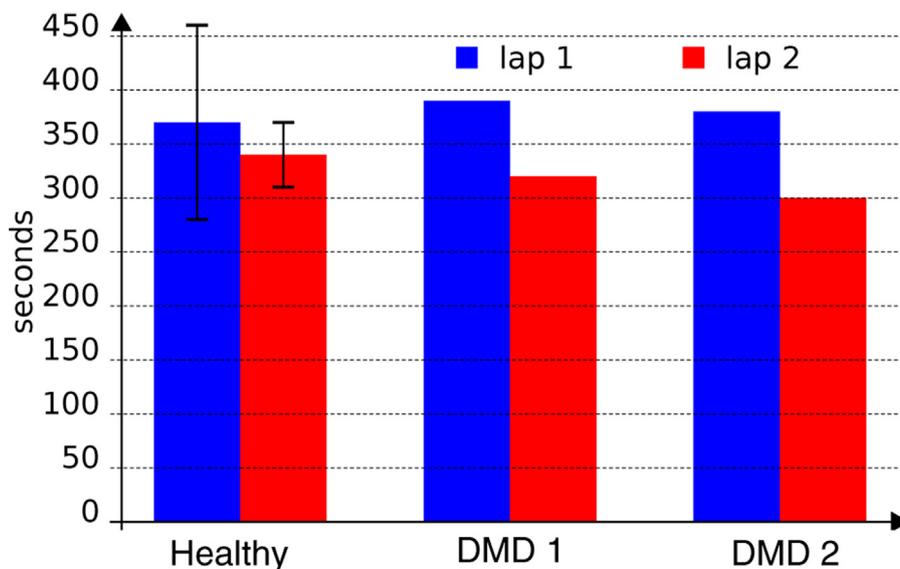


Fig. 2. Mean lap times for each session performed by healthy participants and each DMD individual.

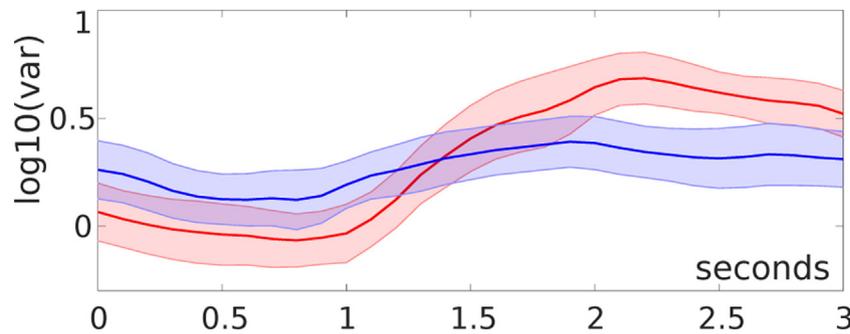


Fig. 3. Mean power levels of electroencephalography signals recorded at electrode C4 for DMD individual 2 (after band-pass filtering in 12–16 Hz of the low β band) under 2 situations: moving both hands simultaneously (red curves) and all other conditions (blue curves).

technique with a wider range of applications, we will ask participants to perform other video-game-based tasks (maze exploration and mouse-like cursor control) developed in our lab with Unity3D software. To assess all the components of our hBMI, we plan to process offline all the recorded EEG signals, which should enable the identification of neurophysiological patterns [2] of value for detecting real or intended hand movements as accurately as possible and thus develop an interface that matches the individual's level of motricity.

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Disclosure of interest

The authors declare that they have no competing interest.

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