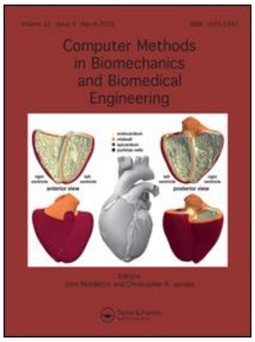

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Analysis of human-exoskeleton interactions: an elbow flexion/extension case study

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KEYWORDS Human/robot interaction; motor control; rehabilitation; physical ergonomics

1. Introduction

Human movement may be affected by different motor deficits such as musculoskeletal disorders (MSDs) in an occupational context or hemiplegia/hemiparesis following a stroke. On the one hand, MSDs are mainly situated in the upper limbs and they represent the first occupational disease in Europe at the present time (INRS 2015). They are partly due to awkward postures and muscle efforts in response to high force requirements during a professional task. To decrease MSDs, upper-limb exoskeletons may be employed (Sylla et al. 2014). On the other hand, 130,000 strokes occur each year in France (INSERM 2013). They are responsible for most of the acquired motor disabilities in adults, with hemiplegia and hemiparesis as main consequences. Upper-limb motor control recovery may be improved via assistive technologies like upper limb exoskeleton (Lo & Xie 2012).

Despite their theoretical advantages, e.g. gestures repeatability or intensive use for long periods (Lo and Xie 2012), the efficiency of exoskeletons for human motion assistance has not yet been significantly proven (Veerbeek et al. 2017). This weakness may be related to the lack of understanding about how humans interact with an exoskeleton: does the motion differ from the nominal one when the exoskeleton is supposedly 'transparent'? How do people adapt movement kinematics and muscle activities? Some researchers addressed similar questions in the past, but the motor task concerned complex three dimensional movements with few repetitions and participants, which made difficult to draw definite conclusions (Jarrassé et al. 2008; Jarrassé et al. 2010; Pirondini et al. 2016). In contrast, the present study focused on simple elbow flexions/extensions performed without and with an exoskeleton (programmed in transparent mode), for different ranges of motion and for several repetitions.

2. Methods

2.1. Participants

18 participants took part in this study. Mean age, height and weight were 24.3 ± 5.0, 177.4 ± 9.8 cm, 71.4 ± 13.0 kg, respectively.

2.2. Materials

The ABLE upper-limb exoskeleton was used in this experiment (Garrec et al. 2008). Based on Screw and Cable System actuators (Garrec 2010), it presented 5° of freedom (3 at the shoulder joint and 2 at the elbow joint) but mainly the forearm flexion/extension was involved here. It was adjusted to the participant's shoulder height and his/her arm was attached to the exoskeleton using straps. A wireless goniometer (Biometrics Ltd) was used to measure elbow joint angle during the movement (1000 Hz). The wrist was fixed in a neutral position using wands during the experiment. Wireless EMG sensors (Biometrics Ltd) were sampled at 2000 Hz and placed on four muscle bellies: biceps brachii, long head of triceps brachii, lateral head of triceps brachii and brachioradialis. EMG and goniometers were synchronized through specific acquisition software (Data Analysis, Biometrics Ltd).

2.3. Procedure

Each participant was asked to perform right-sided pointing movements via elbow flexions/extensions. Five ranges of motion were tested in a randomized order: −50°, −30°, −10°, 10°, 30°, 50°. The participant began and finished his motion at -50° with a 2 s stop at the reversal point. The 0° value corresponded to the forearm being parallel to the horizontal plane. 10 repetitions at each range of motion were recorded. The participant randomly performed these tasks with or without the exoskeleton first (one condition with and one condition

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without). Each participant performed 100 movements (5 amplitudes x 10 repetitions x 2 conditions). Only the results for an upward motion of 80° are presented in this abstract.

3. Results and discussion

3.1. Kinematics

The effective movement was considered when the elbow angular velocity exceeded 1°/s.

Results showed that the mean movement time was significantly larger when wearing ABLE (t = 13.3, p < .001). Accordingly, the mean value of the peak velocity was significantly smaller with ABLE (t = 22.7, p < .001) (Figure 1).

3.2. Muscle activity

EMG Signals were rectified and low-pass filtered (Butterworth, cut-off frequency at 20 Hz) and the motion-related RMS was calculated. The mean RMS value for biceps brachii was significantly higher without ABLE (t = 4.9, p < .001). The same result was obtained for the long and lateral heads of triceps brachii (t = 2.2, p < .05 and t = 4.8, p < .001, respectively). There was no significant difference for the mean RMS value of brachioradialis (Figure 1).

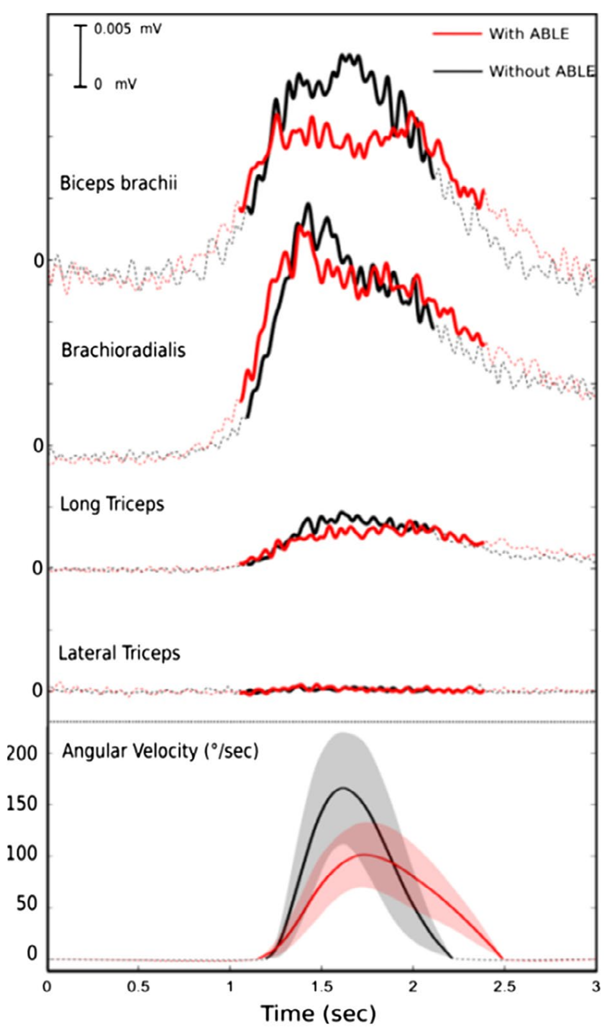

Figure 1. Smoothed-rectified EMGs of biceps brachii, brachioradialis, long and lateral heads of triceps brachii, and corresponding angular velocity (±SD) during an elbow flexion with/without exoskeleton.

4. Conclusions

Spatiotemporal and *in situ* characteristics of the movement were clearly influenced by the interaction with the exoskeleton although it was programmed in transparency mode. Overall, wearing ABLE led to a clear slowing down of spontaneous motion pace. Jarrassé and colleagues also observed this reduction of speed during 3D pointing movements with and without ABLE (Jarrassé et al. 2010). This implicit slowing down of movement might be due to the fact that compliant (with exoskeleton) and unconstrained (without exoskeleton) movements involved different control strategies (Desmurget et al. 1997) and to interaction forces. Additionally, the muscle RMS was larger without exoskeleton, which may appear surprising at first. However, faster movements were observed in that condition, which may explain why overall larger muscle activity was found without ABLE (Weeks et al. 1991). This study provides preliminary insights about the influence of wearing an exoskeleton on elbow flexion/extension movements.

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