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The Effect of Passive Exoskeleton on Shoulder Muscles Activity during Different Static Tasks

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Abstract. In this study we used the bipolar surface electromyography to investigate whether a passive exoskeleton reduces the degree of activity of four shoulder muscles during four different static postures: (P1) shoulder abducted at 90°, elbow flexed at 90°, elbow pronated at 90°; (P2) shoulder flexed at 90°, elbow flexed at 90°, elbow pronated at 90°; (P3) shoulder flexed at 90°, elbow pronated at 90°; (P4) shoulder abducted at 90°, elbow pronated at 90°. Our main statistical results showed a significant ($p<0.05$) attenuation effect of exoskeleton on the RMS amplitude computed for all muscles evaluated, though not for all postures. For the anterior, medial deltoids and upper trapezius a lower level of activity was observed in all postures with than without exoskeleton, while for posterior deltoid only for P2-P3 and P1-P4 respectively. These findings suggest the passive exoskeleton evaluated in this study attenuates the shoulder muscles' effort during static work-related tasks, with implications on the prevention of musculoskeletal disorders.

Keywords: Passive Exoskeleton, Surface Electromyography, Work-related disorders.

1 Introduction

In the occupational sector work-related musculoskeletal disorders (WMSDs) are common among employees, who usually report excessive discomfort and pain at shoulder region [1]. The risk factors usually associated with WMSDs are repetitive or sustained tasks, muscle overload and incorrect postures [2]. Preventive ergonomic approaches have been proposed to reduce the occurrence of WMSDs, such as modification of workstations [3]. Studies have observed passive exoskeletons are a promising technology to reduce muscular loading, perceived effort and discomfort during working tasks [4,5], attracting a great interest in industry. However, it is still an open question and we intend to study here whether the effects of a passive exoskeleton for shoulder support generalize to different muscles and to different static working conditions. We expected a lower degree of muscle activity with than without the use of passive exoskeleton in all static conditions according to previous literature [4,5].

2 Methods

2.1 Participants and experimental conditions

Twelve young healthy volunteers (20-30 years) were recruited and asked to provide a written informed consent before participating in the study, which was conducted in accordance with the *Declaration of Helsinki*. Afterwards, subjects were instructed to perform four static tasks in two conditions, without and with the passive exoskeleton (Muscular Aiding Tech Exoskeleton - MATE, Comau S.p.a, Turin, Italy; Fig.1A). The tasks consisted in maintaining four different postures for 20 seconds five consecutive times each, with a rest time in-between of 20 seconds. The postures studied were: (P1) shoulder abducted at 90°, elbow flexed at 90°, elbow pronated at 90°; (P2) shoulder flexed at 90°, elbow flexed at 90°, elbow pronated at 90°; (P3) shoulder flexed at 90°, elbow pronated at 90°; (P4) shoulder abducted at 90°, elbow pronated at 90°. The standard anatomical position was considered for the description of all joint movements indicated above and tasks were performed in random order. The tasks were selected from two sessions of the Ergonomic Assessment Work-Sheet (EAWS): *Postures and movements* and *Upper limb.*

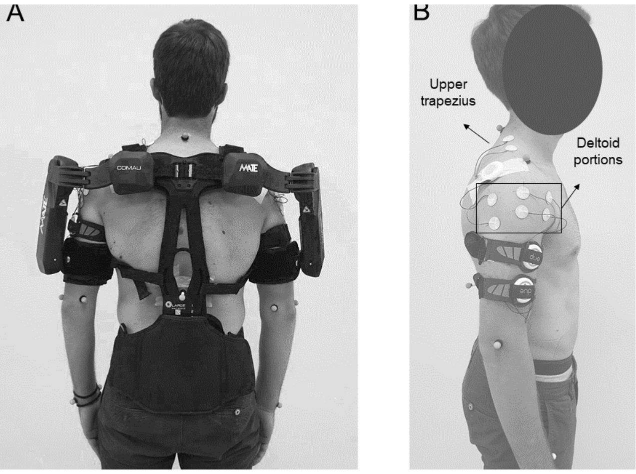

Fig. 1. (A) Posterior view of subject while wearing the exoskeleton MATE. (B) Positioning of a pair of electrodes on the four upper limb muscles tested (lateral view).

2.2 Data recording and analysis

After shaving and cleaning the skin with abrasive paste, pairs of surface electrodes (30 mm inter-electrode center-to-center distance, 24 mm diameter, Spes Medica, Battipaglia, Italy) were used to collect surface electromyograms (EMGs) from the following muscles of the right upper limb (Fig.1B): anterior, medial and posterior deltoids and the upper trapezius. Bipolar EMGs were recorded with a wireless system (200 V/V gain; 10–500 Hz bandwidth amplifier; DuePro system, OTBioelettronica and LISiN, Politecnico di Torino, Turin, Italy) and digitized at 2,048 Hz with a 16 bits A/D converter. Kinematic data, captured by a 12 camera VICON system (100 Hz, Vero v2.2, Nexus 2.9 software, Oxford, UK) through retro-reflective markers positioned in the upper limbs, were recorded simultaneously with EMGs in order to segment them according to movement phases and verify whether subjects maintained correctly the postures.

For all conditions, individual sustained phases (cycles) were first identified from the angular variations of shoulder joint. After the identification of cycles, the segmented bipolar EMGs were band-pass filtered with a fourth order Butterworth bidirectional filter (15–350Hz cut-off) and the level of muscle activity was estimated from the Root Mean Square (RMS) amplitude of surface EMG. The RMS amplitude was computed over epochs corresponding to the sustained phases (providing a total of 5,00 RMS values per muscle), without considering the first and last second of cycle to ensure periods of constant muscle activity. Afterwards, for each condition and muscle, we average the RMS amplitude across cycles, providing a global indication of the level of muscle activity.

2.3 Statistical analysis

Data normality and the homogeneity of variance were respectively tested with Shapiro-Wilk and Levene's statistics. Differences in the RMS amplitude were assessed with two-way ANOVA separately for each posture, with condition (with and without exoskeleton) as repeated measures (2 conditions x 4 postures). Whenever any significant difference was revealed by ANOVA, paired comparisons were assessed with the Tukey-HSD post-hoc test.

3 Results

Data from a representative subject and for an individual static cycle are shown in Fig.2A. Specifically, surface EMGs with relatively low amplitude were observed for all portions of deltoid while this specific participant maintained *Posture 4* using exoskeleton. When considering group data, a main effect of condition was observed for anterior and medial deltoids and upper trapezius, with lower RMS values with than without exoskeleton ($F>6.10$; $p<0.018$ for all cases; Fig.2B). In addition, significant interaction was observed for posterior deltoid, with post-hoc comparisons revealing lower amplitude values with than without exoskeleton for *Postures 1 and 4* ($F>3.53$ and $p<0.025$ for all cases; Fig.2B).

4 Discussion

Our key results revealed the attenuation effect of exoskeleton on muscle activity was manifested at all muscles evaluated, though not for all postures. Marginal muscle contribution for the maintenance of postural task may account for no significant differences in muscle activity between conditions for a given posture. These results corroborate previous findings on lower levels of shoulder muscles' activity with than without the use of passive exoskeletons [4,5]. Therefore, the passive exoskeleton MATE seems to be potentially relevant to avoid overload of shoulder muscles during static contractions, with implications on the prevention of musculoskeletal disorders in industrial manufacturing demanding various manual overhead works.

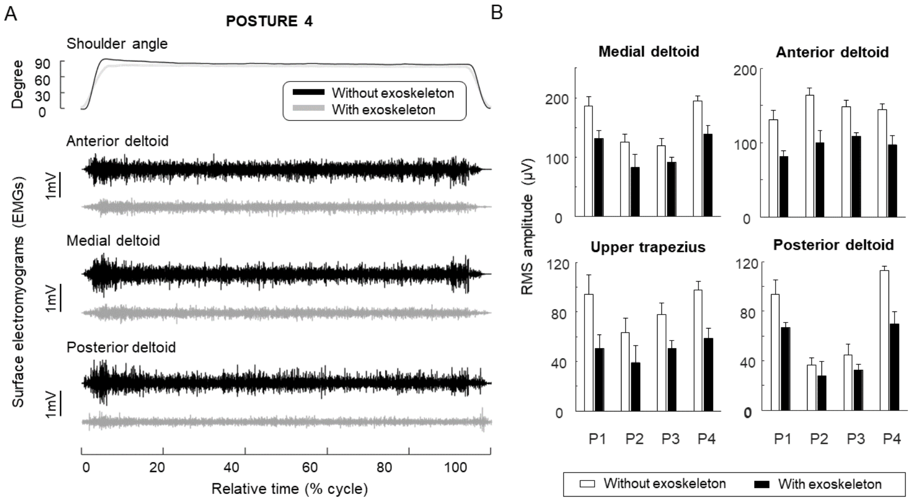

Fig. 2. (A) Shoulder angle in the frontal plane and EMGs sampled from the three portions of deltoid muscle while subject maintaining the *Posture 4* for 20 seconds with and without exoskeleton. Note surface EMG with relatively low amplitude for all three portions of deltoid muscle while using the passive system. (B) Mean (bars) and standard error (whiskers) RMS amplitude values for both conditions are reported for all muscles and postures evaluated.

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