

Assessment of Exoskeleton Related Changes in Kinematics and Muscle Activity



Fabio V. dos Anjos, Taian M. Vieira, Giacinto L. Cerone, Talita P. Pinto, and Marco Gazzoni

Abstract Work-related musculoskeletal disorders, reported at shoulder and low back regions, rank among the most serious health problems in industry. Owing to their ability in providing support to the shoulder and back regions during sustained and repetitive tasks, passive exoskeletons are expected to prevent work-related disorders. In this work, experimental protocols were conducted for the extraction of relevant information regarding the neuromuscular activation and kinematics during simulated working activities with passive exoskeletons. Our results support the notion these passive exoskeletons have the potential to alleviate muscular loading and therefore to prevent musculoskeletal disorders in the industrial sector.

1 Introduction

EXOSKELETONS have been proposed as a promising solution for the prevention of work-related musculoskeletal disorders (MSD) [1, 2]. However, the current knowledge does not fully clarify the impact of exoskeletons on MSD prevention [3]. *Even if many factors must be considered in MSD prevention, excessive muscular stress*

F. V. dos Anjos

Postgraduate Program of Rehabilitation Sciences, Augusto Motta University (UNISUAM), Rio de Janeiro, Brazil

e-mail: fabioanjos@souunisuam.com.br

T. M. Vieira · G. L. Cerone · T. P. Pinto · M. Gazzoni (✉)

Laboratory for Engineering of the Neuromuscular System (LISiN), Politecnico di Torino, Torino, Italy

e-mail: marco.gazzoni@polito.it

T. M. Vieira

e-mail: taian.vieira@polito.it

G. L. Cerone

e-mail: giacintoluigi.cerone@polito.it

T. P. Pinto

e-mail: talita.peixoto@polito.it

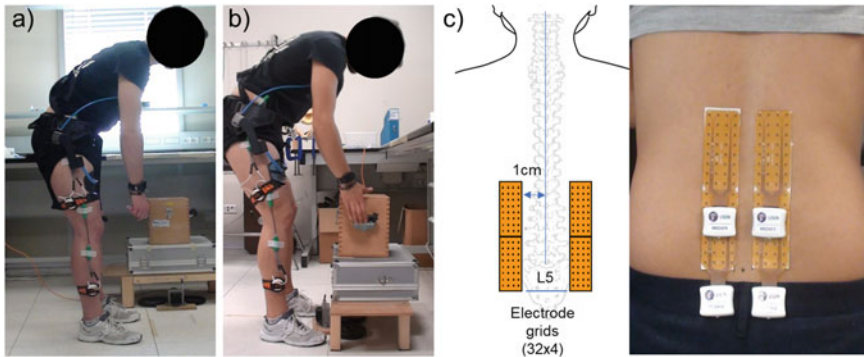


Fig. 1 The static **a** and dynamic **b** tasks used to evaluate changes in muscle activity induced by the Laevo exoskeleton. **c** Surface EMG was acquired using four matrices (16×4 electrodes) positioned over the lumbar muscles bilaterally

is a predominant risk factor. *Consequently*, surface electromyography (sEMG) is an important tool for the evaluation of exoskeleton effectiveness, providing information about changes in muscle efforts. Exoskeletons showed a clear potential in limiting local muscular demand, however, great differences in the reduction of muscle activity are reported in literature [3]. *In this work* we studied the changes in EMG activity and kinematics induced by the use of two passive exoskeletons: one for lumbar support (Laevo V2.5—Laevo B.V., Delft, Netherlands) and one for upper limb support (MATE, Comau S.p.a, Turin, Italy).

2 Material and Methods

2.1 Lumbar Support—Laevo

Ten male volunteers were recruited (age: 22–32 years).

(1) Tasks

Participants were asked to perform one static and one dynamic task, with and without the passive exoskeleton. The static forward bending task consisted in maintaining a 45° trunk flexion posture (Fig. 1a) until exhaustion. In the dynamic task, participants were instructed to repetitively lift and lower a box (mass: 10 kg) between two surfaces at 50 cm and 100 cm from the ground level (Fig. 1b). The task was repeated for 10 min with a frequency of 15 times per minute. A digital metronome was used to assist subjects in complying with the requested cadence.

(2) Electromyography and kinematics

Monopolar sEMG signals were collected *from the low back muscles bilaterally with four electrode grids (8 × 4 electrodes, inter-electrode distance: 10 mm; Fig. 1c) organized in two groups of 32 × 4 electrodes. Signals were conditioned and sampled using four 32 channel acquisition systems for HD-sEMG (2048 samples/s; 16-bit) (LISiN, Politecnico di Torino and OT Bioelettronica) [4]. Hip and knee joint angles of the right leg were collected from two electrogoniometers (Twin-Axis Electrogoniometer SG150, Biometrics Ltd., Newport, United Kingdom), with zero degrees corresponding to full knee and hip extension.*

(3) *Data processing and statistical analysis*

For the static task, Root Mean Square (RMS) values were computed from single-differential EMGs over 1s epochs, while for the dynamic task, RMS values and maximum and minimum joint angles were calculated over individual lifting-lowering cycles. RMS maps were obtained by averaging RMS values at 10% increments in time over the duration of task. For each task, the degree of activity was computed from the maps at the beginning, mid and end of task as the average RMS over the channels showing an RMS value higher than 70% of the maximum RMS in the map [5]. The coordinates of the centroid of RMS distribution along the cranial-caudal direction were also computed. About the kinematic data, the average maximum and minimum angles were extracted from the first, middle and last decile of task for both lifting and lowering. A 2-way and 3-way ANOVA were applied separately for each cycle phase to respectively assess the effect of Time and Device on the joint angles and the effect of Time, Device and Side on the degree of activity and the centroid of RMS distribution (*post-hoc* Tukey and significance level of 5%).

2.2 Upper Limb Support—MATE

Twelve young healthy volunteers (age: 20–30 years) participated in the study.

(1) *Tasks*

Subjects were instructed to maintain four static postures (Fig. 2a) for 20s in two conditions (without and with the passive exoskeleton MATE). The considered postures 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°. Each task was repeated 5 consecutive times. The assistance level was set as recommended by the manufacturer in relation to height and weight of the user.

(2) *Electromyography and kinematics*

Bipolar EMGs were collected from the anterior, medial and posterior deltoids and the upper trapezius of the right upper limb using pairs of surface electrodes (30 mm



Fig. 2 **a** shows the four static postures considered in the study. **b** shows one subject wearing the MATE exoskeleton in posture P3. **c** The positioning of EMG electrodes

inter-electrode distance, 24 mm diameter, Spes Medica, Battipaglia, Italy) and digitized at 2048 Hz with a 16 bits A/D converter (DuePro, OTBioelettronica and LISiN, Politecnico di Torino, Turin, Italy). Kinematic of upper limbs were recorded simultaneously with EMGs by a 12 camera VICON system (100 Hz, Vero v2.2, Oxford, UK), positioning the markers according to the protocol proposed by Hebert et al. [6].

(3) *Data processing and statistical analysis*

For each investigated muscle and posture the average RMS amplitude was computed across the 5 repetitions. Differences in RMS amplitude were assessed with 2-way ANOVA separately for each posture, with condition (with and without exoskeleton) as repeated measures (2 conditions \times 4 postures). Whenever any significant difference was revealed paired comparisons were assessed with Tukey-HSD post-hoc test.

3 Results and Discussion

3.1 *Lumbar Support—Laevo*

Statistical analysis revealed lower level of lumbar muscles' activity ($\sim 10\%$) with than without exoskeleton throughout static task ($F = 10.61$, $p < 0.01$) together with a redistribution of muscle activity (~ 0.5 cm) in the caudal direction toward the end of task ($F = 4.11$, $p < 0.02$). In the dynamic task, a significant attenuation effect of exoskeleton on muscle activity was observed at the beginning of task ($F > 4.97$, $p < 0.01$ in both phases) during both lifting ($\sim 5\%$; $p = 0.01$) and lowering ($\sim 8.5\%$; $p <$

0.01). A trend toward a redistribution of muscle activity to the distal muscle region during the task (~ 0.5 cm; $F = 2.60$, $p < 0.09$) was observed without than with the use of exoskeleton. This finding seems to indicate that exoskeleton may reduce muscle loading at the beginning of the task. Moreover, for the knee joint, a lower maximum angular position ($\sim 6.5^\circ$) was observed with than without exoskeleton, regardless of cycle phase (Device effect: $F > 8.72$, $p < 0.01$; *post-hoc*: $p < 0.01$), suggesting exoskeleton might affect the range of motion during the dynamic task.

3.2 Shoulder Support—MATE

A main Device effect 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). Significant interaction was observed for posterior deltoid, with lower amplitude values with than without exoskeleton for P1 and P4 (*post-hoc* $F > 3.53$ and $p < 0.025$). These findings revealed the attenuation effect of exoskeleton on muscle activity was manifested at all muscles evaluated, though not for all postures when considering posterior deltoid.

4 Conclusion

The results suggest the passive exoskeletons tested seem to be potentially relevant to attenuate the muscular effort, with implications for the prevention of work-related musculoskeletal disorders. The extension of the study to dynamic conditions with the MATE exoskeleton is ongoing.

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