Applied Ergonomics 67 (2018) 211–217

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Physiological consequences of using an upper limb exoskeleton during manual handling tasks

Jean Theurel*, Kevin Desbrosses, Terence Roux, Adriana Savescu

Working Life Department, National Research and Safety Institute, 54 500 Vandœuvre les Nancy, France

ARTICLE INFO

Keywords:
Workload
TMS
EMG

ABSTRACT

This study aimed to assess the physiological consequences of using an upper limb exoskeleton during manual handling task, as muscle activity, upper limb kinematics, postural balance and cardiac cost. Participants performed three tasks (load lifting (LIFT), carrying (WALK) and stacking-unstacking (STACK)) with (EXOS) and without (FREE) an exoskeleton. During LIFT and STACK, the activity of the deltoid anterior muscle was significantly lower for EXOS than for FREE. During LIFT, the activity of the triceps brachii (TB) and tibialis anterior muscles significantly increased for EXO. The TB muscle activity significantly decreased for EXOS during WALK. The cardiac cost tended to increase with the use of the exoskeleton during LIFT, compared to FREE. The upper limb kinematics significantly differed between the EXOS and FREE conditions for all tasks. The benefits of the upper limb exoskeleton to reduce shoulder flexor muscle activity has been demonstrated, while broader physiological consequences have also been evidenced as increased antagonist muscle activity, postural strains, cardiovascular demand, and modified kinematics.

1. Introduction

Manual handling activities are known to expose individuals to considerable biomechanical strains and risks of musculoskeletal disorders (MSD) (Ayoub, 1982; Cole and Grimshaw, 2003; Rempel, 1992; Straker, 1999). Despite the development of modern technology, many jobs still require manual handling tasks so that more than 40% of workers in the European Union continue to suffer from back and shoulder pains (Eurofound, 2012). To deal with this prevalence of MSDs in handling tasks, research is now focusing on new issues, such as the use of exoskeletons (de Looze et al., 2016). Defined as wearable, mechanical structures that enhance the strength of a person, occupational exoskeletons have been designed to physically assist workers in performing their tasks, and thus reduce their exposure to the associated physical demand.

Previous studies have examined the benefits of these new technologies on musculoskeletal strains, focused in particular on devices specifically developed to assist spine erection during trunk bending. The use of back exoskeletons appears to efficiently reduce the activity of low back muscles (Abdoli et al., 2006; Bosch et al., 2016; Frost et al., 2009; Whitfield et al., 2014), local muscular fatigue (Godwin et al., 2009; Lotz et al., 2009), and the internal forces applied to the lumbar spine (Abdoli-Eramaki et al., 2007; Graham et al., 2009) during handling tasks. However, little information is known on the potential benefits of upper-limb exoskeletons regarding the biomechanical strains associated with manual handling tasks. These tasks are also commonly incriminated in the occurrence of shoulder MSD, particularly due to the combination of heavy load carrying, shoulder solicitations in flexion and abduction, and overhead work (OHW) (Frost et al., 2002; Miranda et al., 2005; Roquelaure et al., 2011; Silverstein et al., 2008; van Rijn et al., 2010). Designed to reduce the physical strains placed on the shoulders, upper limb exoskeletons commonly features one or two mechanical arms, fixed on a rigid jacket. A spring system designed to raise the arms provides physical assistance. To our knowledge, these exoskeletons have been specifically assessed during OHW (Rashedi et al., 2014; Sylla et al., 2014). In both studies, the experimental task consisted to a simulated intermittent OHW, in a standing position, where the participants had to holding and handling different tools or payloads (from approximately 1 to 8 kg) over the head. The first results nonetheless demonstrated the potential of the assistive devices to reduce the perceived exertion, shoulder flexor muscle activity (Rashedi et al., 2014), and shoulder joint torque (Sylla et al., 2014).

Therefore, it is interesting to examine the impacts of using these technologies on shoulder biomechanical strains during other handling activities than OHW. It is essential to ensure that upper limb exoskeletons also provide a real advantage for shoulder MSD prevention, without causing other biomechanical strains. For example, previous studies have demonstrated that the use of similar devices could involve

* Corresponding author. INRS, 1 Rue du Morvan, 54 500 Vandœuvre les Nancy, France. Tel.: +33 3 8350 98 84.
E-mail address: jean.theurel@inrs.fr (J. Theurel).

http://dx.doi.org/10.1016/j.apergo.2017.10.008
Received 23 June 2017; Received in revised form 29 September 2017; Accepted 11 October 2017

significant postural changes during OHW (Sylla et al., 2014) and kinematics stains (Ulrey and Fathallah, 2013). Moreover, increased lumbar muscle activity has been observed during OHW with a customised upper limb exoskeleton, compared to an identical task, performed without assistance (Rashedi et al., 2014). The inertial characteristics (i.e. mass and balance) of upper limb exoskeletons could partly explain the latter observations. It can also be expected that the postural changes resulted to modifications in the motor pattern of the upper limbs (i.e. focal muscular chain), due to kinematics strains. Furthermore, the increase of postural strains associated to the increase of muscle activity could have significant repercussions on metabolic responses.

The present study aimed to assess the impact of using an upper limb exoskeleton on focal and postural muscle activity, upper arm kinematics and cardiac cost during handling tasks.

2. Materials and methods

2.1. Participants

Four women (31 ± 2 years, 166 ± 4 cm, 62 ± 10 kg) and four men (33 ± 3 years, 179 ± 3 cm, 78 ± 3 kg), right-handed, without back or shoulder pathologies, volunteered to participate in this study. Their usual work tasks mainly consisted in the manual handling of different boxes. They were trained (97 ± 18 min) to perform the experimental tasks during 4 sessions, with and without an exoskeleton. They had given their written consent after receiving detailed information on the objectives, protocol and possible risks. The experimental protocol received approval from the ethical committee of the company, including the medical staff and union representatives. Each volunteer participated in the present study after a medical examination.

2.2. Experimental tasks

The participants had to perform three modalities of handling tasks according to the present protocol, each of them with (EXOS) and without (FREE) an exoskeleton, in random order. These experimental tasks consisted successively in load lifting in the sagittal plane (LIFT), walking while carrying a load (WALK), and manual load handling with a 90°-rotation in the longitudinal axis (STACK) (Fig. 1). The two conditions (EXOS and FREE) were separated by a recovery period of 20 min, in a sitting position.

2.2.1. Exoskeleton

The EXHAUSS Stronger® exoskeleton (EXHAUSS, France) was used in this study. It weighs 9 kg and consists of two mechanical arms activated by springs. The arms are linked to a rigid wearable jacket, with joints, allowing free 3D movements. The distal extremities of the mechanical arms have short belts used to strap the user's hand (Fig. 1). This exoskeleton provides non-linear arm lift assistance over an angular range from 0° to 135° of the shoulder anterior flexion. The assistive torque can be adjusted by prestressing the springs. In this study, we adjusted the system so that the exoskeleton provided a force assistance of ≈9 kg for men and ≈5 kg for women at the arm end of the exoskeleton for a 90° shoulder anterior flexion. These values were in accordance with the loads handled by each group during the LIFT condition. The participants had to handle routine materials (toolboxes) during the WALK and STACK tasks. The exoskeleton was adjusted to the anthropometric characteristics of the subjects.

2.2.2. Load lifting and lowering task (LIFT)

The LIFT task was a standardized task consisting in load lifting from a low platform to a high one, and vice versa for 3 min at an imposed rate, using a rhythmic beep (ten cycles/minute). One full cycle included both load lifting and lowering actions. The two platforms faced the participant so as to limit the movement in the sagittal plane. These platforms were adjusted to the anthropometric characteristics of the workers, at knee and shoulder height, respectively. The high platform was positioned behind the low one, so as to obtain a complete elbow extension in the sagittal plane (Fig. 1, A). The load was adjusted to 9 kg for men and 5 kg for women, respectively. This difference was related to the maximum strength of the men and women observed for anterior shoulder flexion during the pre-tests (100% vs. 56%). A recovery period of five minutes was provided after the task.

2.2.3. Walking with load carrying task (WALK)

WALK consisted in walking over a distance of 30 m at a free chosen (as usual working tasks) speed, carrying a two-handled toolbox (Fig. 1, B). For each experimental condition (EXOS vs. FREE), the task was repeated four times and a break of 10 s was given between each repetition, done by releasing the toolbox. The toolbox weight was adjusted to 15 kg for the men and 8 kg for the women. A 5-min recovery period was provided after the entire task.

2.2.4. Box unstacking and stacking task (STACK)

STACK consisted in unstacking and stacking 4 boxes (≈80 cm wide and 35 cm high) with a 90° rotation of the operator on its longitudinal axis (Fig. 1, C). The full unstacking and stacking of the 4 boxes was considered as a cycle. The subjects had to perform eight full cycles to complete this experimental task. Contrary to LIFT, the workers were not subjected to any imposed pace (as usual working tasks). The free pacing advised was defined as “normal for a 5 min work period”. The boxes weighed 15 kg for the men and 8 kg for the women.

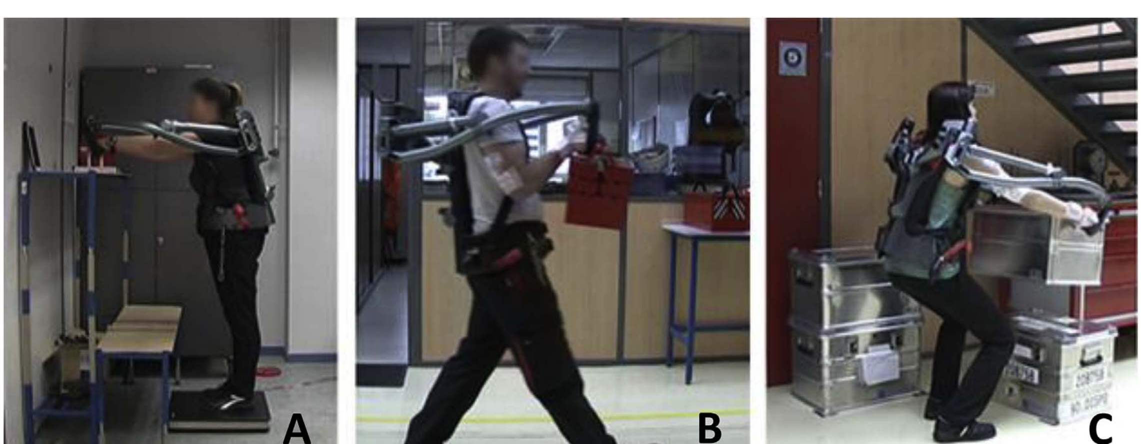

Fig. 1. Experimental tasks. Each participant performed a LIFT task (A), a WALK task (B) and a STACK task (C), with and without an upper limb exoskeleton.