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The effects of a passive exoskeleton on muscle activity, discomfort and endurance time in forward bending work

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A B S T R A C T

Exoskeletons may form a new strategy to reduce the risk of developing low back pain in stressful jobs. In the present study we examined the potential of a so-called passive exoskeleton on muscle activity, discomfort and endurance time in prolonged forward-bended working postures.

Eighteen subjects performed two tasks: a simulated assembly task with the trunk in a forward-bended position and static holding of the same trunk position without further activity. We measured the electromyography for muscles in the back, abdomen and legs. We also measured the perceived local discomfort. In the static holding task we determined the endurance, defined as the time that people could continue without passing a specified discomfort threshold.

In the assembly task we found lower muscle activity (by 35–38%) and lower discomfort in the low back when wearing the exoskeleton. Additionally, the hip extensor activity was reduced. The exoskeleton led to more discomfort in the chest region. In the task of static holding, we observed that exoskeleton use led to an increase in endurance time from 3.2 to 9.7 min, on average.

The results illustrate the good potential of this passive exoskeleton to reduce the internal muscle forces and (reactive) spinal forces in the lumbar region. However, the adoption of an over-extended knee position might be, among others, one of the concerns when using the exoskeleton.

1. Introduction

Work-related musculoskeletal disorders (WMSDs) affect a considerable proportion of the working population. Of all WMSDs 30% are located in the low back region (Eurostat, 2010). Low back pain (LBP) frequently results in sick leave and disability, and thus, puts a large burden on individuals and the society (Goetzel et al., 2003). The development of work-related LBP has been associated with several work factors, among others lifting and carrying of loads and awkward body postures like trunk flexion and rotation (Griffith et al., 2012; Da Costa and Vieira, 2010). Hereto, various preventive measures have been proposed, e.g. the training of workers, the adjustment of work stations, the re-organization of work processes, and the use of mechanical aids like cranes or balancers (Lavender et al., 2013). From the developments of new technologies, other potentially preventive strategies emerge. One of these could be the use of exoskeletons.

An exoskeleton is a wearable device supporting the human to generate the physical power required for manual tasks. Exoskeletons could be useful, when (i) other preventive measures are not feasible, usable or effective, and (ii) where the automation of tasks is not feasible when tasks constantly change (e.g. the job of movers, unloading loose loads from containers, patient handling). Exoskeletons could be classified as 'active' or 'passive' (Lee et al., 2012). An active exoskeleton is comprised of one or more actuators (e.g., electrical motors) that actively augments power to the human body. A passive system does not use an external power source, but uses materials, springs or dampers with the ability to store energy from human movements and release it when required.

Active exoskeletons have been particularly developed for the purpose of rehabilitating injured or disabled people. Active exoskeletons with an occupation or industrial purpose are being developed, but these are mainly in a laboratory stage now (e.g., Kadota et al., 2009; Lee et al., 2012; Luo and Yu, 2013; Looze de et al., 2015).

On the other hand, several passive systems ready to be used in work situations, have been described in the literature. These

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include the Personal Lifting Assistive Device (PLAD) and the Bending Non-Demand Return (BNDR). Both devices consist of a frame that stores elastic energy when bending forward, which then helps a person to prolong bent-forward working postures or to erect the body again when lifting an object. The BNDR frame covers the trunk and pelvis and is supported by the upper legs and chest (Ulrey and Fathallah, 2013a). The final version of PLAD frame supports sharing of the load between the spine, shoulders, pelvis and feet (Whitfield et al., 2014).

For the PLAD, significant reductions of the back muscle activity during lifting have been reported (Abdoli-Eramaki et al., 2008; Lotz et al., 2009; Whitfield et al., 2014) and during static bending (Graham et al., 2009). For the BNDR, the back muscle activity was studied in a constrained isometric posture by Ulrey and Fathallah (2013a). They found a reduction of muscle activation in a subselection of their study population (namely only in those subjects not experiencing the flexion-relaxation phenomenon when adopting isometric torso flexion postures).

In the current study, the effect of a passive exoskeleton was studied on the activity of the back muscles during a simulated assembly task with the trunk in bent forward position. We additionally measured the muscle activity of the abdominal muscles and the hip extensor to study the occurrence of any potential negative side effects. We also measured local perceived discomfort. In a separate task, namely in static holding of the upper body in forward flexion, we studied the effect of the exoskeleton on endurance time.

2. Methods

2.1. Participants

In this study eighteen healthy participants (nine male, nine female, mean age was 25 (SD 8) years, mean body mass was 71 (SD 12.4) kg and mean height 1.76 (SD 0.1) m), volunteered to participate in the study. None of the participants reported low back pain in the previous three months. Subjects signed an informed consent, after being informed about procedures of the experiment. The study was approved by the Ethics Committee of VU University Amsterdam.

2.2. Passive exoskeleton

In the study, a passive exoskeleton (Laevo, Delft, The Netherlands) was used as presented in Fig. 1. This exoskeleton consists of three types of pads: two chest pads, one back pad and two (upper) leg pads. On both sides of the body, the pads were connected through a circular tube with spring like characteristics. The exoskeleton is intended to transfer forces from the lower back to the chest and leg pads.

2.3. Procedure

Participants performed two different tasks, i.e. assembly work and a static holding task, with and without wearing the exoskeleton. All subjects started with the assembly task, followed by the holding task. The order of the two conditions (with and without exoskeleton) within the tasks was systematically varied across subjects. To familiarize the participants with the experimental equipment and procedure, a training session was performed prior to the first condition. All sessions were performed in a laboratory at a constant ambient temperature of 22 °C.

Fig. 1. The passive Laevo exoskeleton used in the current study.

2.4. Tasks

2.4.1. Task 1 – simulated assembly

The first task involved repetitive pick and place actions so as to simulate industrial assembly work as described by Bosch et al. (2011). The task was performed using a Perdue pegboard (Purdue Pegboard Model 32020; Lafayette Instrument Company, Lafayette, IN, USA) centrally positioned in front of the participant. Participants had to pick, place and remove 10 pairs of pins in a fixed order with the left and right hand simultaneously on the beat of a metronome (2/3 Hz). Bins with these components were placed to the left and the right of the participant (Fig. 2). Working height was standardized placing the table surface 15 cm below the participants Trochanter Major. At the start and end of each work cycle, participants had to move the two bins to a fixed position at shoulder height in front of them and push a red button at the right side of the Pegboard. When performing the pick and place actions participants adopted a 40° trunk flexion (defined as the angle between the line from L5-C7 with the vertical, Fig. 2A). In between pick and place work cycles participants had to adopt an upright neutral posture, with the hands hanging alongside the body for 30 s. In total ten work cycles were performed.

To control the predefined trunk flexion angle during the assembly task, feedback on the body posture was given to the subjects by the experimenter using the Ergomix (Hallbeck et al., 2010). Two parallel lines with a 40° angle were projected and presented to the subject. The subjects had to keep their trunk between these two