Testing the efficacy of an ergonomic lifting aid at diminishing muscular fatigue in women over a prolonged period of lifting

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ABSTRACT

A personal lift assist device (PLAD) was designed with passive elastic elements that act with a similar line of action to the spine muscles and reduce the extension moment experienced during lifting activities. The purpose of this paper was to evaluate the device's ability to reduce fatigue during a repetitive lifting task. Women ($n = 12$) lifted a box load representing 20% maximal extensor strength repetitively (12 lift/lowers per minute) for 45 min while electromyography (EMG) was recorded from the lumbar and thoracic erector spinae, and cardiovascular measures were monitored. Subjects were also tested on strength and endurance tests prior to, and after lifting. The increase in EMG RMS amplitude from the start until the end of the lifting session was significantly lower when wearing the PLAD for the TES (91% vs 3%) and the LES (104% vs 16%). The median frequency (MF) drop was also significantly lower when wearing the PLAD for TES and LES. The PLAD delayed the onset of fatigue in women by requiring less muscular effort.

Relevance to industry
There are numerous industries that still require repetitive manual materials handling tasks to be performed by humans. Repetitive lifting fatigues the musculature involved and may lead to an increased risk of injury. The PLAD reduced fatigue on several measures. This device appears to have potential for industries where women perform repetitive, fatiguing lifts.

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1. Introduction

The prevalence of musculoskeletal disorders (MSD) and low-back pain (LBP) in industrial workplaces has been recognized as a significant cost to companies, society and the health care system (Andersson, 1997; Woolf and Pfleger, 2003). In an effort to reduce the number of lost days due to manual materials handling (MMH) related injury (and the associated costs), companies often decide to implement mechanized lift systems as a control strategy meant to alleviate the physical demands present in repetitive tasks. Already of significant cost, mechanized lift systems can be quite limited in terms of versatility as they are typically customized to the workstation, and inherently feature a fixed range of motion (ROM). For these reasons, an assistive device that could be worn on-the-body may serve as a viable option for offloading the erector spinae

muscles during MMH tasks; ultimately reducing operator physical demands, regardless of workstation location and/or adopted posture.

Throughout the last several years, we have attempted to refine such a technology within our laboratory. As a result, the Personal Lift Assist Device (PLAD) has undergone numerous design iterations but the basic concept has remained unchanged. The PLAD is designed to assist the erector spinae musculature in MMH tasks and static postures by utilizing elastic energy that is stored during trunk/knee flexion and returned during subsequent trunk/knee extension. Two elastic elements are attached to shoulder straps at the upper ends. The lower ends are attached to cables that travel to the feet via an attachment at the knee and pulleys that offset the moment arm at the pelvis by 15 cm. The laboratory prototype (Fig. 1) used in the current paper has recently been modified for use in acceptability trials within the automotive industry.

A mathematical proof has suggested that the PLAD provides a mechanical advantage over the lumbar extensors for stooped and squat posture lifting (Abdoli-Eramaki et al., 2007). As such, the

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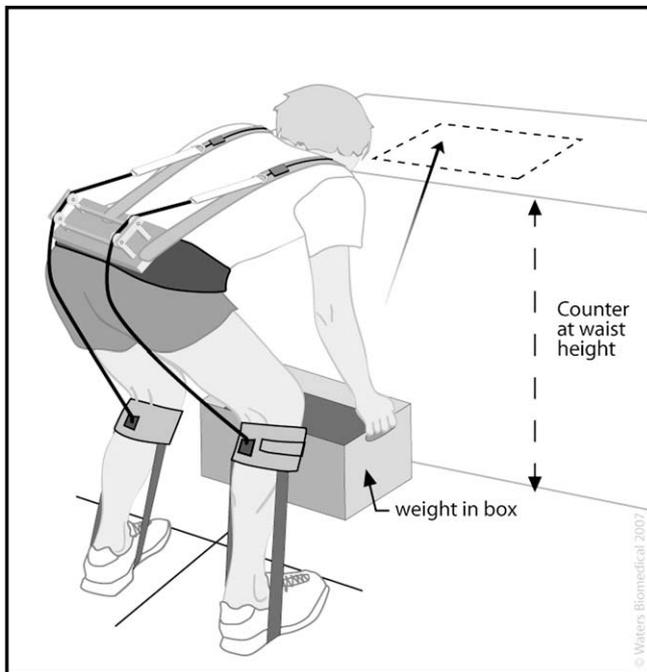 E-mail address: agodwin@laurentian.ca (A.A. Godwin).

Fig. 1. A sketch of the PLAD design iteration used in this study.

assistive nature of the device was empirically shown using male participants by reducing the net moment experienced at the L4/L5 spinal level by 14%–20% (Abdoli-Eramaki et al., 2006) and by decreasing the EMG amplitude of the extensor muscles during symmetric lifts by 14%–27% (Abdoli-Eramaki et al., 2006). These studies involved controlled lifting scenarios using a specified lift technique with a protocol that did not fatigue the subjects. Recently, a fatigue-inducing investigation by Lotz et al. (in press), also demonstrated that the PLAD reduced the amount of localized fatigue manifested within the lumbar and thoracic erector spinae muscles throughout a repetitive lifting task. However, at this point it is unknown whether the PLAD will elicit the same response when it is used by females.

Despite more females entering occupations with MSD risks, little work has been done to specifically improve their work environment (Punnett and Herbert, 2000) and they continue to report more musculoskeletal pain symptoms than men at a similar exposure level(Dahlberg et al., 2004). Investigations regarding strength differences between genders suggest that males have a clear advantage for performing MMH tasks due to longer limbs, longer moment arms for torso muscles (Jorgensen et al., 2001) and larger muscle fibers (Miller et al., 1993; Mannion et al., 1997, 1998). However, different kinematic strategies (Marras et al., 2002), a potentially more coordinated style of lifting (Lindbeck and Kjellberg, 2001) and a slightly different neuromuscular activation pattern (Lariviere et al., 2006) may lead to a more efficient lifting style in females over prolonged work periods. Given these adaptations to prolonged lifting, there is a need to document how the PLAD device affects biomechanical and physiological measures for women during a prolonged working task.

This research sought to fatigue female subjects in the same manner as a previous study completed on males (Lotz et al., in press). Women were asked to lift at the same work rate, same relative workload, and with the same PLAD elastic elements, as the men. Since women are typically lighter than men, with a lower center of gravity and smaller trunk mass, it was hypothesized that the PLAD may have a more beneficial effect for women than men. The goal of this paper was to determine if the PLAD could reduce

back muscle fatigue and cardiovascular fatigue for women performing repetitive lifts over a prolonged period of time.

2. Methods

Physically active, female subjects ($n = 12$) with no history of back pain were recruited from a university population. Average subject characteristics were 30 ± 13 years of age, 170 ± 1.7 cm and 69.3 ± 6.6 kg. A repeated measures design was used where subjects participated in three sessions: an orientation session to obtain baseline measures on endurance and strength tests followed by two testing sessions designed to elicit muscular fatigue through repetitive lifting. A set of isometric reference contractions were performed after every 5 min block of lifting across 45 min so that reliable measures of EMG fatigue could be acquired.

2.1. Instrumentation and data processing

2.1.1. Cardiovascular monitoring
Heart rate data were recorded using an on-chest digital heart rate monitor with chest strap (Timex Corp, CT). This hardware was used to record subject's resting heart rate, and subsequent changes in heart rate that occurred during the lifting trials. To do so, the average heart rate over the last 5 s of every minute of lifting was manually observed and recorded. Minute heart rates were averaged to produce a mean heart rate for each 5-min block and normalized to heart rate range (HRR) using an age-predicted maximum heart rate and the observed resting heart rate value.

Subjects were also asked to verbally rate their level of physical exertion using the Borg Rating of Perceived Exertion (RPE) Scale. At the end of every minute of lifting, subjects were asked to rate their perceived level of exertion using a scale that ranged from 6 to 20. Using these data, an average RPE rating was then produced for each 5-min block of lifting.

2.1.2. EMG monitoring
Surface electromyography (EMG) sites on the right-hand side of body were prepared by abrading the skin with alcohol. Ag-AgCl conductive adhesive electrodes (MediTrace, The Ludlow Company LP, MA) were affixed superficially to the thoracic erector spinae (TES) at the T9 level (3 cm lateral) and lumbar erector spinae (LES) at the L3 level (5 cm lateral), using an inter-electrode distance of 3 cm with a reference electrode placed on the C7 spinous process (SENIAM, 2005). Signals were conditioned using a Bortec AMT8-channel differential amplifier (Bortec Biomedical Ltd, AB, Canada) with 10GΩ input impedance and Common Mode Rejection Ratio (CMRR) of 115 dB and a 1000 gain setting. The EMG signals were captured digitally at 1024 Hz using a 12-bit A/D card (National Instruments, Austin, TX), bandpassed at 20–450 Hz and then stored for processing using custom software (LabView, National Instruments, Austin, TX).

2.1.3. Isometric testing device
Isometric back extensor strength and endurance tests as well as all reference contractions were completed on a modified ARCON© Functional Capacity Evaluation System that was outfitted with an adjustable padded harness that featured an in-series load cell (Interface SM S-Type, Scottsdale, AZ) (Fig. 2). A height-adjustable pelvis restraint provided a line-of-action through the Anterior Superior Iliac Spine (ASIS). Subjects were restrained under the armpits and asked to keep their knees straight and hands behind their heads in order to target back extensors at the thoracic and lumbar level only. Data from the load cell (volts) were sampled at 1024 Hz, captured with a 12-bit A/D card (National Instruments, Austin, TX) calibrated to represent force output (N) and digitally low pass filtered at a cutoff frequency of 10 Hz using custom software (LabView, National Instruments, Austin, TX).