Evaluation of a Trunk Supporting Exoskeleton for reducing Muscle Fatigue

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Although the effect of wearing a back-support exoskeleton during lifting has been demonstrated to reduce overall muscle activation, less is known about how wearing exoskeletons affect muscular fatigue and oxygen consumption. The purpose of this study is to evaluate the effect of wearing a back-support exoskeleton (backX) on muscle fatigue during repetitive lifting by assessing whether wearing backX increases endurance time relative to lifting unassisted. A secondary objective of this study is to quantify changes in oxygen consumption rate while performing a repetitive lifting task with and without backX to address a common industry concern. The UC Ergonomics Lab evaluated backX on twelve male subjects by measuring bilateral muscle activity of the erector spinae and oxygen consumption rate. Summary measures of muscle activity for 50 and 90 percent of the repetitive lifting session were used to characterize peak and mean muscle activity. Oxygen consumption rate was collected continuously during the repetitive lifting session. Compared to the unassisted condition, wearing backX reduced peak lumbar erector spinae activation by 16.5% and 21.8% ($p < 0.05$). The time subjects could hold a back-straining posture after the repetitive lifting session increased by 52% after wearing backX during the lifting task. The was no significant negative change in oxygen consumption rate. This study confirms that wearing a backX reduces muscle activation in the lower back for this specific dynamic lifting task. Additionally, we find that wearing a backX may reduce the risk of low back injuries by reducing muscle activity and increasing endurance time to fatigue

INTRODUCTION

Background

Recent studies by the U.S. Department of Labor continue to identify back injuries as the most common and costly work related injury (Bureau of Labor Statistics, 2005, 2010, 2015). Back injury can occur when the applied load on the tissue exceeds the failure stress in that tissue or through repetitive loading of the muscle tissue until failure (McGill, 1997; Phinyomark, Thongpanja, Hu, Phukpattaranont, & Limsakul, 2012). Local muscle fatigue occurs during repetitive loading of muscle tissue, is defined as the progressive loss of force generating capacity of the muscle, and has been associated with increased risk of musculoskeletal injury (Bigland-Ritchie & Woods, 1984; Phinyomark et al., 2012).

Multiple wearable exoskeleton devices have been commercialized to reduce back muscle activity while lifting (Babcock, n.d.; Frost, Abdoli-E, & Stevenson, 2009; Laevo B.V., 2015; US6436065 B1, 2002; US5951591 A, 1999). backX (suitX, Emeryville, CA) is a wearable exoskeleton that reduces back muscle activation when the user bends forward.

Objectives

The amount of time a person can maintain a specific level of muscle activity until exhaustion (endurance time) decreases after performing a fatiguing task (Enoka & Stuart, 1992; Potvin & Norman, 1993). Therefore, the objective of this study was to evaluate the effect of wearing backX on muscle fatigue during repetitive lifting and lowering by assessing whether wearing backX increases endurance time. Additionally, a common industry concern is whether workers will incur a higher oxygen demands while wearing an exoskeleton (Lowe, Dick, Hudock, & Bobick, 2016); thus, a secondary objective was to evaluate how wearing backX affects oxygen demand during repetitive lifting tasks.

METHODS

Orientation

Eleven male subjects with an average age of 31.1 years (SD = 10.2) participated in this within-subjects laboratory study. After providing informed consent, participants completed a baseline survey and electromyographic (EMG) electrodes (Noraxon, Scottsdale, Arizona) were attached over the right and left lumbar erector spinae (RLES, LLES) and thoracic erector spinae (RTES, LTES). backX was then adjusted to fit the subject's body dimensions.

To measure maximum voluntary contraction EMG activity (MVC) for each muscle group, subjects were instructed to incline their upper body to horizontal while in the Roman chair with their feet secured, grasp a floor-mounted strap, then extend their back with maximum effort for 3 seconds. This procedure was repeated three times. MVC for each muscle was recorded as the maximum EMG signal measured in that muscle over the course of these three trials. Subjects did not wear backX while eliciting MVC measurements.

Experimental Protocol

Subjects first performed an endurance test where each subject was in a prone position on a Roman chair with their feet secured, then held their upper body at a 45° angle while holding a 5 kg weight until they could no longer hold their body at the 45° angle (test posture). The duration that the subject could hold the test posture prior to performing any work was measured before (pre-work endurance time) and after (post-work endurance time) each work session. The work session consisted of lifting and lowering an 18 kg load at 7 lifts/minute for 4 minutes. These endurance tests and work session were repeated for each subject with and without backX in a randomized order. EMG data was collected at 1500 Hz continuously during work and endurance tests and normalized to the subject's MVC. Summary measures of EMG amplitude probability distribution functions for 50 (APDF50) and 90 (APDF90) percent of the work session were estimated and normalized against MVC for each muscle group to quantify mean and peak muscle activation levels. Metabolic changes were quantified by oxygen consumption (Metamax, Leipzig, Germany).

RESULTS

Compared to the unassisted condition, use of backX during the repetitive lifting task reduced peak thoracic and lumbar erector spinae muscle activity (Figure 1). RLES and LLES EMG activation when wearing the backX were at or below 62.6% and 57.4% of MVC for 90% of the work session, respectively, compared to 75.0% and 73.4% of MVC when not wearing backX. For 50% of the work session, RLES and LLES activation was at or below 24.3% and 23.3% of MVC when wearing backX, compared to 29.2% and 27.3% of MVC while not wearing backX. Reduction for peak muscle activation for RLES and LLES were statistically significant ($p < 0.05$).

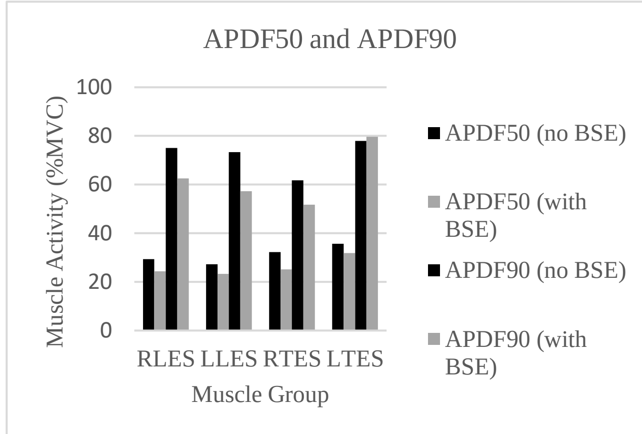

Figure 1: APDF50 and APDF90 for the erector spinae. Differences in APDF90 for RLES and LLES were statistically significant ($p<.05$).

Additionally, comparing endurance times with and without backX suggests that the work session was less fatiguing when performed wearing backX. Post-work endurance time was 74% of the pre-work endurance time after wearing backX, but only 50% of the pre-work endurance time after not using backX during the work session.

Wearing the backX resulted in no significant increase in oxygen consumption rate. Oxygen consumption rate per kg of body mass while wearing backX was 14.7 mL/kg/min after 2 minutes of lifting and 15.2 mL/kg/min after 4 minutes of lifting, but results were not statistically significant. Oxygen consumption rate while lifting without backX was 14.4 mL/kg/min after 2 minutes and 15.7 mL/kg/min after 4 minutes of lifting. However, oxygen consumption rate during the work session increased at 0.88 mL/kg/min^2 when lifting with the backX compared to 1.6 mL/kg/min^2 when lifting without the backX.

DISCUSSION

Muscle Activity

The results of this study indicate that wearing backX during a lifting task reduces muscular activation of the erector spinae. Peak muscle activation for RLES and LLES was reduced by 16.5% and 21.8%, respectively, when wearing backX ($p < 0.05$). This Reduction in peak and median muscle activation for RLES, LLES, RTES, and LTES is consistent with various studies showing reduction of back muscle activation while wearing a back support exoskeleton to perform a lifting task (Frost et al., 2009; Godwin et al., 2009a; Lotz, Agnew, Godwin, & Stevenson, 2009; Whitfield, Costigan, Stevenson, & Smallman, 2014).

Fatigue

Post-work endurance time increased by 52% after performing the repetitive lifting task with backX. Increased post-work endurance time and reduced muscle activation is congruent with reduced muscle fatigue after repetitive lifting (Godwin et al., 2009b; Lotz et al., 2009; Potvin & Norman, 1993). Reduction in muscle activity increases post-work endurance time (Enoka & Stuart, 1992), hence the observed increase in post-work endurance time after wearing backX is likely attributed to the reduction in erector spinae muscle activity from wearing backX to perform the lifting task.

Metabolic changes

Wearing the backX had no negative effects on oxygen consumption rate, consistent with findings from Whitfield et al. (Whitfield et al., 2014). Differences in oxygen consumption rate with backX (SD = 1.2 mL/kg/min) and without backX (SD = 1.8 mL/kg/min) across all subjects may have been due to fitness levels or how the subjects used the backX. Some subjects lean forward into the device and allow gravity to instigate forward movement of the trunk, rather than pushing deliberately into the device to force forward bending of the trunk, the latter of which requires more effort. However, oxygen consumption rate increased more slowly when lifting with the backX. This was likely due to subjects becoming more comfortable with consciously reducing lower back muscle activity as they adapted to the assistance provided by the backX.

CONCLUSION

This study confirms that wearing a backX reduces muscle activation in the lower back for this specific dynamic lifting task. Additionally, we find that wearing a backX may reduce the risk of low back injuries by reducing muscle activity and increasing endurance time to fatigue.

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