Applied Ergonomics 75 (2019) 1–7

Contents lists available at ScienceDirect

Applied Ergonomics

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

Impact of two postural assist exoskeletons on biomechanical loading of the lumbar spine

Michael T. Picchiotti[a,b], Eric B. Weston[a,b,*], Gregory G. Knapik[a,b], Jonathan S. Dufour[a,b], William S. Marras[a,b]

[a] Spine Research Institute, The Ohio State University, Columbus, OH, USA
[b] Department of Integrated Systems Engineering, The Ohio State University, Columbus, OH, USA

ARTICLE INFO

Keywords:
Assistive device
Low back pain
Passive exoskeleton
Ergoskeleton

ABSTRACT

This study evaluated loading on the low back while wearing two commercially available postural assist exoskeletons. Ten male subjects lifted a box from multiple lift origins (combinations of vertical height and asymmetry) to a common destination using a squatting lifting technique with and without the use of either exoskeleton. Dependent measures included subject kinematics, moment arms between the torso or weight being lifted and the lumbar spine, and spinal loads as predicted by an electromyography-driven spine model. One of the exoskeletons tested (StrongArm Technologies™ FLx) reduced peak torso flexion at the shin lift origin, but differences in moment arms or spinal loads attributable to either of the interventions were not observed. Thus, industrial exoskeletons designed to control posture may not be beneficial in reducing biomechanical loads on the lumbar spine. Interventions altering the external manual materials handling environment (lift origin, load weight) may be more appropriate when implementation is fesible.

1. Introduction

Low back disorders (LBDs) remain prevalent for workers around the globe and carry a significant social and economic burden (NRC, 2001). In the United States, 80% of the population will suffer low back pain (LBP) at some point in their lifetime (Andersson, 1997). LBDs have become a leading reason for physician visits, hospitalization, and utilization of other health care services (Andersson, 1999) and are the cause for approximately 149 million lost work days per year (Guo et al., 1999). LBDs also carry a large economic burden, with the annual direct cost of treatment totaling over $100 billion in the United States alone (Katz, 2006).

Though LBDs are prevalent in a variety of occupational environments, jobs involving manual materials handling remain among the riskiest. As such, several interventions have been made available to assist workers in their occupational activities. Some of these include lift tables, cranes, balancers, and other lift assist devices (Lavender et al., 2013). These devices can be beneficial for the workers but may also have drawbacks in that they can be costly, space consuming, and underutilized if the loads to be lifted fall within the capabilities of the worker (Graham et al., 2009). In order to address some of these limitations, industrial exoskeletons have recently been designed and integrated into various industry settings as a workplace intervention. These exoskeletons enable humans to more safely generate the physical power required for a given task (Bosch et al., 2016; de Looze et al., 2016).

While some “active” exoskeletons contain one or more actuators that assist the human body by actively augmenting power using batteries or electric cable connections (de Looze et al., 2016; Gopura and Kiguchi, 2009; Lee et al., 2012), the majority of exoskeletons designed for industrial work are considered “passive.” Passive devices are more readily adopted due to their lower cost and ease of implementation into occupational environments. The appearance and functions of the commercially available passive devices available are vast, dependent on the supported body part(s) and mechanism being used for support. For example, some passive exoskeletons rely on springs, dampers, or materials capable of storing energy from the movement of the body and releasing it when necessary (Bosch et al., 2016; de Looze et al., 2016). Common to most of these devices is their focus on imposing a restorative force, such as one that aims to return the user to a neutral posture when the torso is flexed.

To date, there have been numerous biomechanical studies using electromyography (EMG) data, kinematic measures, or complex biomechanical modeling techniques to evaluate passive exoskeletons that

---

[*] Corresponding author. 1971 Neil Avenue Rm 512, Columbus, OH, 43210, USA.
E-mail address: weston.101@osu.edu (E.B. Weston).

https://doi.org/10.1016/j.apergo.2018.09.006
Received 6 June 2018; Received in revised form 6 September 2018; Accepted 8 September 2018

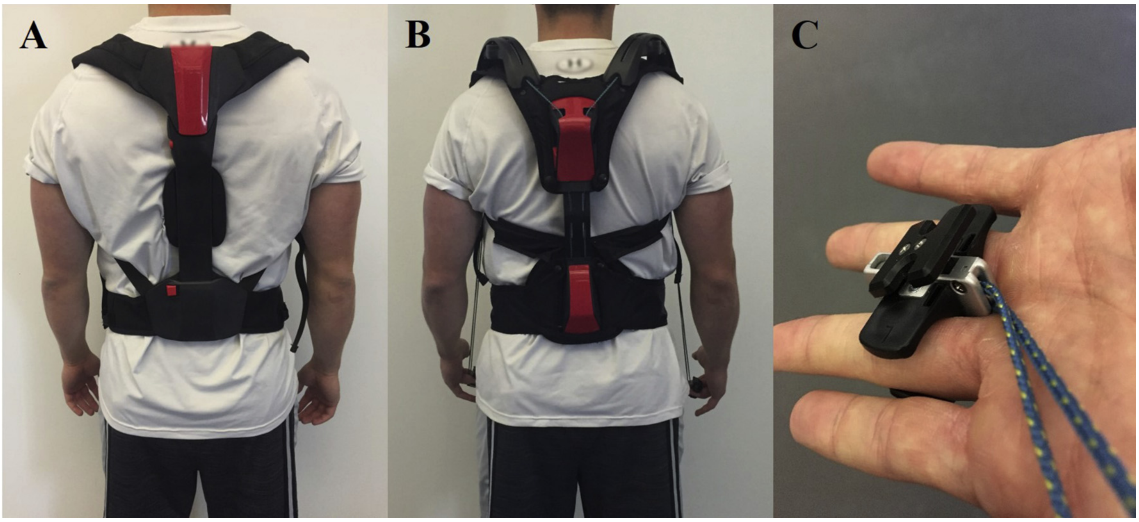

Fig. 1. Photos showing postural assist exoskeletons tested including **(A)** the FLx **(B)** the V22 and **(C)** the hand effector of the V22.

provide a restorative force to the user in some capacity (Abdoli-E et al., 2006; Abdoli-E and Stevenson, 2008; Abdoli-Eramaki et al., 2007; Bosch et al., 2016; Frost et al., 2009; Godwin et al., 2009; Graham et al., 2009; Heydari et al., 2013; Lotz et al., 2009; Ulrey and Fathallah, 2013a; b; Wehner et al., 2009; Weston et al., 2018). However, no studies have evaluated an even simpler class of passive exoskeletons, one that does not provide any restorative force to the user. Relying instead on assisting its users to adopt more favorable postures in an attempt to reduce biomechanical risk, this class of exoskeleton is less expensive than other passive exoskeletons on the market, making them a potentially attractive purchase for companies. However, implications surrounding the use of this latter type of passive exoskeleton are not as well understood. Given, too, that the influence of lifting technique (such as stoop vs. squat) on low back pain outcomes is still a matter of debate (Dreischarf et al., 2016; Hsiang et al., 1997; van Dieen et al., 1999), it remains unclear what benefit passive exoskeletons designed solely for postural guidance might have on biomechanical risk measures.

Thus, the objective of this study was to employ a complex biomechanical model to understand the effects of two postural support exoskeletons on subject kinematics and biomechanical loading of the lumbar spine during a controlled lifting task. Given that subjects would experience the same load regardless of whether either exoskeleton was being worn or not worn (no restorative force), it was expected that only subtle (if any) improvements to biomechanical measures would be observed.

2. Methods

2.1. Approach

Two different commercially available exoskeletons (details below) were evaluated and compared to a no exoskeleton-use condition as subjects lifted from several typical origins to a common destination in a laboratory setting. Basic biomechanical measures included joint flexion angles and the horizontal moment arm from the torso and load being lifted to L5/S1. Research has demonstrated that tissue loading logic provides a more clear picture of injury risk than assessing EMG activity or posture alone (Marras, 2012), so assessing exoskeleton effectiveness from a complex biomechanical tissue loading perspective was preferable in this investigation. Thus, an EMG-driven dynamic biomechanical spine model was also employed to evaluate peak spinal loads in compression, anterior/posterior (A/P) shear, and lateral shear along the length of the lumbar spine extending from T12/L1 to L5/S1. This biomechanical model is well validated and has been described extensively in the literature (Dufour et al., 2013; Granata and Marras, 1993, 1995; Hwang et al., 2016a, 2016b, 2017; Marras and Granata, 1997). It relies on subject-specific anthropometry, MRI-derived muscle locations and sizes (Jorgensen et al., 2001; Marras et al., 2001), full body kinematics, kinetics, muscle activity for the power producing muscles of the torso, and tissue material properties as model inputs to ultimately predict dynamic tissue loads.

2.2. Subjects

Ten male subjects were recruited locally (mean age 24.9 ± 5.0 years (SD), range 22–38 years; mass 81.1 ± 16.1 kg, range 63.4–102.7 kg; height 179.4 ± 4.6 cm, range 172.1–186.4 cm). This sample size was deemed appropriate via a power analysis with a power of 0.95 using a one side *t*-test. Subjects recruited for this study reported neither any LBDs nor cases of low back pain in the past 3 years nor any prior low back surgeries. Subjects gave informed consent per a study protocol approved by the University Institutional Review Board.

2.3. Study design

As mentioned in 2.1 (Approach), two commercially available exoskeletons were evaluated in this investigation. The first device tested was a postural assist device properly named the FLx; this exoskeleton (size medium, length 40.7–48.8 cm, weight 1.08 kg) has a rigid plastic rod that extends up the length of the back of its wearer and is worn on the body similar to a backpack, with two torso straps and a hip strap (Fig. 1A). This device was designed to remind the wearer to use proper lifting techniques in order to reduce the risk of injury, primarily by discouraging both extensive torso flexion and twisting, which are known risk factors for LBDs (Marras et al., 1993, 1995). When standing in a neutral posture, the FLx remains unengaged; however, as its user bends forward or twists, the device applies pressure on the user's back as feedback and a reminder to return to a more neutral posture. The second device tested, properly named the V22 (size medium, length 41.9–52.1 cm, weight 1.29 kg), is similar to the FLx but the notable difference between the two is that the V22 also contains cables extending from the shoulders (Fig. 1B). These cables terminate at two effectors worn on the hands (Fig. 1C) between the middle and ring fingers that were designed to lock the cables into place as the user of the device lifts and carries a particular load. As such, the intent of this device is to not just serve as a postural assist device but also to transfer biomechanical loads from the upper body; the exoskeleton was