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Ergonomic evaluation of standard and alternative pallet jack handless

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ABSTRACT

Aim: Transportation of materials using a pallet jack pulled behind the operator is common due to the visual advantages while transporting fully loaded pallets. The objective of this laboratory study was to quantify muscle activity, posture, and low back compressive and shear forces while completing typical pallet jack activities using a standard handle that required one handed pulling of a pallet jack compared to an alternative handle that allowed for two handed pushing.
Methods: Participants (n = 14) performed six to ten trials of common pallet jack tasks (straight travel and turning) with each handle. Posture analysis of the trunk and right upper extremity was performed using Motion Analysis (Santa Rosa, CA, USA) and back compressive and shear forces were analyzed using 3D Static Strength Prediction Program (University of Michigan, Ann Arbor, MI). Activity of the upper trapezius (UT), pectoralis major (PM), flexor digitorum superficialis (FDS) and extensor digitorum (ED) muscles were recorded (Telemyo 2400 T, Noraxon, Scottsdale, Arizona) and normalized to percent reference voluntary contraction values. All outcomes were compared using the paired *t*-test.
Results: Peak and mean muscle activity of the PM ($p < 0.001$) and ED ($p < 0.01$) were significantly higher using the alternative push handle during all three tasks. There were larger compressive forces at L4/L5 ($p < 0.08$) and L5/S1 ($p < 0.002$) using the alternative handle, and greater shear forces using the standard handle at both L4/L5 ($p < 0.0001$) and L5/S1 ($p < 0.000$).
Discussion: The standard handle outperformed the alternative handle with regard to muscle activity. The alternative handle had significantly greater compressive forces at L5/S1 due to the pushing nature of the hand-handle interface, yet the standard handle increased shear forces at both L4/L5 and L5/S1 levels in the low back.
Conclusion: In this analysis, there was not a clear benefit to using either handle in terms of trunk strength capacity and varied benefits and drawbacks to each handle when comparing compressive and shear forces in the low back. However, given favorable subjective reports described in a prior publication, and the increased reliance on dynamic versus passive force production, facilitating a workers' ability to push a pallet jack while travelling with large loads is worth further investigation.

1. Introduction

A common task in manual material handling (MMH) jobs includes manual transportation of products or materials on a pallet jack to eliminate workers exposure to carrying heavy loads. However, use of pallet jacks poses a risk of injury since they require pushing and pulling forces to maneuver them (Hoozemans et al., 1998). Pushing and pulling activities increase the incidence of self-report shoulder and low back complaints (Hoozemans et al., 2002a, 2002b, 2014). On average between 9 and 18% of low-back injuries are associated with pushing or pulling tasks (Hoozemans et al., 1998). Although, according to the Bureau of Labor Statistics (2009), there were only 2710 lost time injuries from pallet jack use, operators using pallet jacks to move product are typically also responsible for loading and unloading product from the pallet. The lifting and lowering further increases biomechanical exposure placing workers at increased risk for shoulder, distal upper extremity and back injuries (Hoozemans et al., 1998, 2004). Therefore,

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workers who manually transport products by loading and unloading pallet jacks and then pushing or pulling them are at high risk for costly claims, particularly in the lumbar spine (Dunning et al., 2010). Further, it has been documented that low-back pain is the most physically debilitating musculoskeletal disorder (MSD) with symptoms having the highest correlation with reduced health-related quality of life and increased days of sickness absence (Plouvier et al., 2008). In 2004, lost production time due to back pain among workers 40–65 years costs U.S. employers approximately $7.4 billion per year (Ricci et al., 2006), and in 2005 the average total cost of a lumbar disc injury was $52,041, 600% higher cost than any other body part (Dunning et al., 2010). Thus, the high financial and social cost of work related low back disorders require exposure reduction efforts wherever possible.

When a pallet jack is empty or lightly loaded it can be safely pushed in front of the user. However, when travelling with a fully loaded pallet jack the user must pull it behind them to maintain a clear line of sight and avoid collisions. Pulling a pallet jack results in an awkward shoulder and trunk posture that could pose a substantial physical demand on the body when the pallet is heavily loaded (Harris-Adamson and Lin, 2013). The operator's position includes full extension and internal or external rotation at the glenohumeral joint (depending on a supinated or pronated forearm position), twisting of the trunk, and grasping of a handle that is parallel to the frontal plane of the operator, potentially a less advantageous position for generating maximum force and reducing overall exertion (Kumar 1994; Hoozemans et al., 2004). Critical reviews have found strong evidence to support increased risk of low back disorders associated with bending and twisting activities (Marras, 2000). Punnet et al. (1991) found that approximately 75% of the etiology of low back injuries was due to the effects of non-neutral trunk posture including mild to severe trunk flexion and twisting.

The risk of low back disorders from MMH tasks can be analyzed by quantifying compressive, shear, and torsional forces in the spine (Marras, 2000). Based on tissue tolerance for spinal loading, NIOSH has set maximal spinal loading limits including 3400 N of compressive force and 500 N of anterior/posterior (A/P) shear force (NIOSH, 1981; McGill, 2002). Although these thresholds exist, the evidence has been equivocal on whether pushing or pulling imposes more risk for low-back injury based on compression and shear forces at the lumbar spine. Numerous studies suggest that lumbar spine compressive forces are higher when pulling compared to pushing (Knapik and Marras, 2009; Schibye et al., 2001; Hoozemans et al., 2004; Chow and Dickerson, 2015). Yet, Knapik and Marras (2009) found that pushing imposed 23% more A/P shear force than pulling since spinal tissue tolerances, which are greatly affected by load level, repetition, time of day and posture of the spine, are much lower for shear and torsional forces than compressive ones (Marras, 2000). It has been proposed by Marras (2000) that (A/P) shear force may be more important than compressive force if the magnitude of compressive force is below the threshold that causes tissue damage.

The literature provides information on factors that affect push/pull forces such as wheel specifications and handle height (Lee et al., 1991, 2011; Hoozemans et al., 1998; Al-Eisawi et al., 1999; Chow and Dickerson, 2015). The literature also describes how load weight, load control, and speed of activity influence spinal compressive, lateral shear, and A/P shear forces (Marras et al., 2009). However, research comparing pushing versus pulling pallet jacks is limited. Given the high frequency and cost of low back disorders in MMH tasks, including pallet jack use, finding ways to reduce MMH workers' biomechanical exposure is important. Therefore, the goal of this study was to compare pushing versus pulling when the operator travelled with the load behind thereby allowing a clear line of sight.

In a prior publication we explored the subjective and physiological aspects of pushing versus pulling a pallet jack when the operator travelled with the load behind the user. Results showed that there was no substantial difference in the maximum force production required to maneuver the pallet jack (measured via a force transducer in the stem of the handle), yet the physical demand, quantified by higher oxygen consumption and heart rate levels, was higher while pushing the pallet jack versus pulling it (Harris-Adamson and Lin, 2013). Still, subjective ratings indicated improved comfort for all body regions possibly due to the improved posture of the shoulder and trunk and the ability to share the load with two hands versus one. Therefore, this analysis sought to assess whether pushing versus pulling a pallet jack offered biomechanical advantages as measured by lumbar spine forces, trunk posture, muscle activity and strength capacities.

2. Materials & methods

2.1. Participants

The experimental protocols were approved by the Institutional Review Board of the Liberty Mutual Research Institute for Safety. Men between the ages of 18 and 65 years were recruited for this laboratory study. After giving their informed consent, fourteen people agreed to participate. Study participants had an average age of 43.5 years (SD = 14) with the youngest participant being 22 years of age and the oldest being 59. The average height and weight was 178.7 cm (SD = 6.61) and 85.3 kg (SD = 14.8). Heights ranged between 166.5 cm up to 188 cm and weights ranged between 67 kg and 113 kg. Participants were a sample of convenience and were only excluded if they had any current musculoskeletal disorders, cardiovascular conditions, or other adverse physical conditions that would place them at risk during the experiment.

2.2. Intervention: standard pull versus alternative push handles

The alternative handle was a prototype designed by the authors and collaborating scientists in response to shoulder injuries assessed during fieldwork at material handling plants, yet specifically for research purposes. The design goal was to optimize an operator's efficiency and safety by reducing awkward shoulder, trunk, forearm and wrist posture, potentially reducing biomechanical risk to the lumbar spine and shoulder. Participants performed all tasks with a pallet jack carrying a medium load (295 kg) travelling behind them using two different handles (Li et al., 2008). The standard pallet jack handle was a horizontal handle that allowed for a unilateral grip behind the operator (Fig. 1b). The alternative handle was attached to the pallet jack and allowed bilateral gripping in front of the operator (Fig. 1a). The alternative handle (Harris-Adamson and Lin, 2013) was designed as an optional handle for specific use during long travels when the load was pulled behind the operator. Using Fig. 1a and b as an example, if F is the necessary force required to move the load, when pulling the pallet jack (Fig. 1b) the participant shown would have to apply 40% more hand exertion force (cF given $\Theta = 23^\circ$) in order to generate enough horizontal force to pull the load forward. The alternative handle (Fig. 1a) provided greater efficiency by allowing all the participant's push force to be bilaterally directed in the horizontal direction thereby reducing hand exertion force (F/2). The same benefit is appreciated by all participants, albeit slight variations based on the participant's height (affecting Θ and cF) since both the standard and alternative handles were freely adjustable in handle angle (Θ, Fig. 1a and b). The bilateral grip angle was positioned at 15° from vertical in the sagittal plane and 45° from vertical in the