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Are psychophysically chosen lifting loads based on joint kinetics?

Jacob J. Banks*, Graham E. Caldwell

University of Massachusetts, Department of Kinesiology, Amherst, MA, 01003, USA

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ABSTRACT

Tables of maximal acceptable weight limits (MAWL) are used to select safe lifting loads and help reduce workplace injuries. However, their subjective basis provides little information on the underlying load selection rationale, and few studies have examined MAWLs in relation to full-body joint demands. Therefore, link-segment biomechanical modeling was applied for 18 participants during three sagittal 4.3 lifts/minute tasks at chosen MAWL levels. Each lift produced unique kinematics, kinetics, MAWL loads and most highly stressed joints. Lifting from the lowest starting position most heavily challenged the L5/S1 joint, whereas more upright starting postures stressed the shoulder. Lifting loads above and below MAWL level demonstrated consistent joint loading patterns. The normalized peak moments of the highest stressed joint were similar across the lifts at ~70–75% of the joint maximum. Our results suggest that MAWLs may be chosen based on perception of the most stressed joint for the specific lift.

1. Introduction

In a recent Workplace Safety Index, Liberty Mutual Insurance ranked musculoskeletal overexertion as the leading cause of disabling injury at the workplace, associated with an estimated $13.7 billion in national burden during 2015 (Liberty Mutual Insurance, 2018). Though lower back strains are most prevalent, leg and arm disorders also contribute to injuries incurred during manual materials handling tasks such as lifting (Dempsey and Hashemi, 1999). Reducing these injury rates would result in considerable societal savings, and thus is an important objective of ergonomists.

To readily assess the injury risk of lifting tasks in the workplace, researchers have developed biomechanical (Waters et al., 1993; Chang et al., 2003; University of Michigan Center for Ergonomics, 2017) and physiological models (Ayoub and Dempsey, 1999). An important contribution of research into specific lifting tasks has been the development of tables of psychophysically acceptable workloads (Dempsey et al., 2005). Psychophysical tables typically provide information on the maximum quantity of a given stimulus (in this case, lifting load) which participants perceive they can be exposed to without risk of injury (Snook et al., 1970). Psychophysical tables are simple to implement (Dempsey et al., 2005), and have been linked to injury prevention (Liles et al., 1984; Snook, 1985; Herrin et al., 1986). However, such tables are constrained to specific lifting tasks, and the process of creating them is demanding. For manual materials handling, robust tables have resulted from years of dedicated research in which a psychophysical protocol is applied across numerous participants with an array of workplace setups to create guidelines of maximal acceptable weight limits (MAWL) for specific lifting tasks (Ayoub et al., 1978; Mital, 1984; Snook and Ciriello, 1991). Critical for defining a lifting task's MAWL is the reliance of each participant's interpretation of the protocol and their self-perception of personal injury risk (Snook, 1985). But how do these subjective assessments of MAWL values correlate with objective loading measures based on biomechanical modeling?

Historically, research to validate and predict psychophysical limits for lifting based on objective measures has focused on overall lifting capacity (Ayoub et al., 1978; Garg et al., 1982; Foreman et al., 1984; Garg and Badger, 1986; Jiang et al., 1986; Garg and Beller, 1994; Schenk et al., 2006). With biomechanical link-segment models, the computation of joint kinetic variables is a well-established procedure (Bresler and Frankel, 1950) that has been used to quantify differences among lifting tasks (Morris et al., 1961; Fisher, 1967; Chaffin and Baker, 1970; Ayoub and Bassoussi, 1976; Schultz and Andersson, 1981; Jager and Luttmann, 1989; de Looze et al., 1992; Kingma et al., 1996; Plamondon et al., 1996). Some biomechanical variables such as spinal loading and muscular strain have been linked with psychophysical MAWLs during both dynamic and static lifting tasks (Jorgensen et al., 1999; Chen, 2000; Davis et al., 2000; Nussbaum and Lang, 2005; Kuijer

Abbreviations: F-K, Floor-to-Knuckle lift; K-E, Knuckle-to-Elbow Lift; K-I, Knuckle-to-Eye lift; MAWL, Maximal Acceptable Weight Limit; M_j, Joint moment; MVC, Maximal Voluntary Contraction; r_s, Spearman correlation coefficients; ROM, Range of Motion

* Corresponding author.
E-mail address: jbanks@umass.edu (J.J. Banks).

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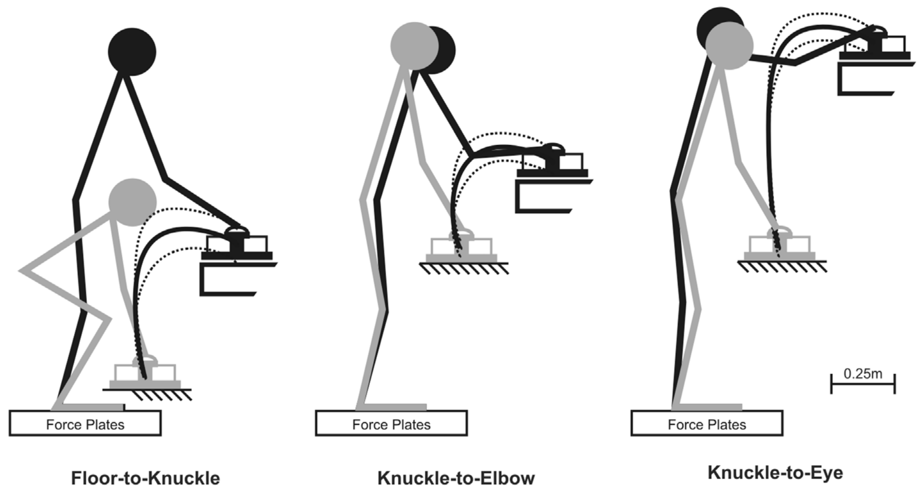

Fig. 1. Initial (grey) and final (black) positioning for the three lifting tasks along with the average (black line) and standard deviation (dotted line) for the box trajectory.

et al., 2012). Despite the inherent full-body coordination typical of lifting (Hsiang and McGorry, 1997) and the variable location of injuries (Dempsey and Hashemi, 1999), there have been no published attempts to examine how psychophysical MAWL selection is related to full-body joint kinetics during dynamic lifting situations. A comprehensive analysis of specific joint demands could objectively differentiate locations of injury risk (Chaffin et al., 1977; Le et al., 2012; Fischer et al., 2012). Moreover, linking MAWL with objective variables could deepen our understanding of the MAWL decision process, allow for a potential expansion of psychophysical tables by way of prediction equations, and address psychophysical table validity concerns (Ayoub and Dempsey, 1999; Fischer et al., 2012; Potvin, 2012a; Fischer and Dickerson, 2014).

Therefore, we sought to better understand the psychophysical MAWL load selection process through objective biomechanical variables. Participant-specific psychophysical MAWL loads were determined for three different sagittal plane lifting tasks chosen to elicit a variety of box trajectories, kinematics and joint loading responses: 1) floor-to-knuckle [F-K], 2) knuckle-to-elbow [K-E], and 3) knuckle-to-eye [K-I] height lifts (Fig. 1). Full-body joint kinematics and kinetics for each lift were derived from motion capture, ground reaction forces, and a rigid-body linked-segment biomechanical model. We hypothesized that at MAWL box load levels, individual lifting tasks (F-K, K-E, and K-I) would elicit lift-specific patterns of joint moments, with the most highly stressed joint varying between the three lifting tasks. To further elucidate the relationship between lifts and joint demands, each lifting task was examined across multiple loads scaled both above and below the self-selected MAWL loads.

2. Methods

2.1. Participants

18 healthy, young, fit male participants (25 ± 5 years; 178 ± 6 cm; 80 ± 10 kg; BMI < 30) with manual materials handling experience were screened to ensure an absence of musculoskeletal injury. All participants provided informed consent to a protocol approved by the Institutional Review Board of the University of Massachusetts Amherst. To limit the effects of fatigue, the data collection protocol was divided into two visits separated by at least 48 h.

2.2. Setup and apparatus

A 34 × 56 × 16 cm lifting box was instrumented with 6-degree of freedom force sensors (AMTI, Watertown, MA) in each handle. The box's evenly distributed mass could be easily adjusted by the addition or removal of steel shot with a hand scoop. To inhibit visual cues of the load mass, the box contained a false bottom where an unspecified amount of additional steel shot was concealed. Participants knew of the false bottom, but not the amount of load concealed. An automated robotic lifting shelf was designed to provide a landing platform for the lifting box, and to repeatedly deliver the box accurately to the initial position. Software adjustments allowed the shelf to accommodate the three prescribed lifting tasks tailored to each participant's anthropometry. An auditory prompt was used to pace the lifts.

Eight passive near-infrared cameras (Motion Analysis Corporation, Santa Rosa, CA) recorded the lifting box and participant motion at 100 Hz using ninety-five 12.5 mm reflective markers. A combination of individual markers and rigid marker clusters were anatomically positioned to define body segment, box, and force sensor locations. Two force plates (Kistler Instruments Corporation, Amherst, NY) and the handle force sensors measured bilateral ground and hand reaction forces, respectively, synchronously recorded within the motion capture software (Cortex 5.5) at 1000 Hz with a 16-bit digital I/O card (National Instruments Corporation, Austin, TX).

2.3. Procedure

Day 1- For warm-up and to acquaint each participant with the automated shelf, 20 knee-to-elbow height practice lifts were performed at 4.3 lifts/minute with a lift load of 9 kgs, the 90th percentile population MAWL value for a similar task (Snook and Ciriello, 1991). No instructions on lifting technique were provided, but participants were restricted to stand with each foot on a separate force plate throughout a lift.

Following practice, a condensed psychophysical protocol was used to efficiently determine the participant's MAWLs for the three lifting tasks (F-K, K-E, and K-I; Fig. 1), each performed at an industry-relevant and protocol-valid rate of 4.3 lifts/minute (Ciriello et al., 1990). For each task, participants lifted the weighted box for two 20-min sessions, beginning with either a heavy or a light initial box mass. During each session, participants were instructed to identify a maximal load they believed safe for a theoretical 8-h work day (Ciriello et al., 1990), by adjusting the amount of steel shot in the box as necessary. The automated shelf returned the box to the starting position in time to make load adjustments within the 4.3 lifts/minute task rate. The final box mass was measured after each of the two sessions, then averaged to determine the participant's MAWL for that task. Presentation order of the initial box mass and the three lifting tasks was randomized, with a 5-min break separating tasks. In all, each participant was exposed to 120 min (2 × 20-min sessions x 3 lifting tasks) of lifting during the Day