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Age-related differences do affect postural kinematics and joint kinetics during repetitive lifting

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ABSTRACT

Background: Age is considered a risk factor for manual handling-related injuries and older workers incur higher injury-related costs than younger co-workers. This study investigated the differences between the kinematics and kinetics of repetitive lifting in two groups of handlers of different ages.

Methods: Fourteen younger (mean 24.4 yr) and 14 older (mean 47.2 yr) males participated in the study. Participants repetitively lifted a box weighing 13 kg at a frequency of 10 lifts/min for a maximum of 20 min. Postural kinematics (joint and lumbosacral angles and angular velocities) and kinetics (joint moments) were measured throughout the lifting task using motion analysis and ground reaction forces. Muscle fatigue of the erector spinae was assessed using electromyography.

Findings: Peak lumbosacral, trunk, hip and knee flexion angles differed significantly between age groups over the duration of the task, as did lumbosacral and trunk angular velocities. The younger group increased peak lumbar flexion by approximately 18% and approached 99% of maximum lumbosacral flexion after 20 min, whereas the older group increased lumbar flexion by 4% and approached 82% maximum flexion. The younger group had a larger increase in peak lumbosacral and trunk angular velocities during extension, which may be related to the increased back muscle fatigue observed among the younger group.

Interpretation: Older participants appeared to control the detrimental effects of fatigue associated with repetitive lifting and limit lumbar spine range of motion. The higher rates of musculoskeletal injury among older workers may stem from a complex interaction of manual handling risk factors.

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1. Introduction

Older workers are at greater risk of injury, more frequently sustain severe injuries, require more leave from work to recover, and incur higher injury-related costs than younger co-workers (Heiden et al., 2013; Holmstrom and Engholm, 2003; Kirkland and Dobin, 2009; Mackey et al., 2007; Peek-Asa et al., 2004). Among older workers, musculoskeletal injuries are one of the most frequent causes of work related ill-health and low back pain is one of the most common and disabling of these conditions (Heiden et al., 2013; Holmstrom and Engholm, 2003; Mackey et al., 2007; Peek-Asa et al., 2004). In 2010–2011, back injuries cost the Accident Compensation Corporation (ACC) of New Zealand an estimated NZ$230 million, with those aged 40 to 54 years contributing to approximately 42% of the total costs (Accident Compensation Corporation, 2012). Internationally the picture is much the same, with 25% of workers in Europe (2005 survey) reporting back pain (European Agency for Safety and Health at Work, 2007) and US estimates placing the total cost of low back pain in excess of $100 billion per year (Katz, 2006).

In the workplace, manual handling is a leading cause of low back pain (Dempsey, 1998). Whilst a number of manual handling risk factors, including age, have been associated with low back injury, their importance to the aetiology of injury is not well understood. Ageing is associated with a progressive decline in physical work capacity, which has been linked to reduced aerobic power and muscle strength, increases in body mass and metabolic costs, loss of skeletal muscle mass (sarcopenia), and neuromuscular changes, e.g. motor unit remodelling (Lanza et al., 2004; Saupe et al., 1991; Shephard, 1999; Singh et al., 2011; Sluiter and Frings-Dresen, 2007; Yassierli et al., 2007).

A high incidence of low back injuries has been reported for those tasks involving repetitive lifting (Dempsey, 1998; Frymoyer et al., 1983; Marras and Granata, 1997; McCoy et al., 1997), which can lead to increased lumbar flexion, increased loading on passive structures of the spine, reduced spinal stability, localised muscle fatigue and acute inflammatory responses in lumbar spine tissue (Dolan and Adams, 1998; Gallagher et al., 2007; Marras et al., 2006; McGill, 1997; Mehta et al., 2014; Yang et al., 2011). Among older workers, these effects may be magnified due to an individual's reduced physical work capacity, thereby placing them at an increased risk of musculoskeletal injury.

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Studies investigating age-related effects of lifting biomechanics have identified differences in trunk and lower limb kinematics between younger and older populations (Burgess et al., 2009; Shin et al., 2006; Song and Qu, 2014). Burgess et al. (2009) suggested that decreased segmental trunk angular kinematics could contribute to increased trunk displacement and place older workers at greater risk of musculoskeletal injury. Song and Qu (2014) implied that reduced trunk flexion and lifting speed among older adults was evidence of 'safer' lifting strategies. Whilst these studies have investigated a range of task parameters (e.g. height of lift, asymmetrical lifting, and weight of load), none have compared time-dependent changes during a repetitive lifting task in populations of different ages.

The aim of this study was to investigate whether there are differences in kinematics and kinetics between a group of younger and older adults when performing a prolonged repetitive lifting task. Understanding the biomechanical differences between these age groups may help to identify the contributory factors leading to the higher injury rates in older workers and provide a basis for targeted musculoskeletal interventions.

2. Methods

2.1. Participants

Twenty eight adult males participated in the study. Fourteen were aged between 20 and 31 years (mean = 24.4 years (yr) (standard deviation (SD) = 3.5 yr)), and made up the group of 'younger' adults. The 'older' group consisted of 14 participants aged 43–54 years (mean = 47.2 yr (SD = 3.4 yr)). Demographics of the two samples are detailed in Table 1. Participants were excluded from the study if they had: undergone previous spinal surgery; a back complaint within the last six months; a cardiovascular or neurological condition; or a musculoskeletal injury at the time of the study. None of the participants were experienced in manual handling, i.e. none regularly undertook manual handling during their normal job. Prior to taking part in the study, participants completed a habitual physical activity questionnaire (Baecke et al., 1982) to determine their general level of physical activity. The study was approved by the University ethics committee.

2.2. Experimental procedure

Participants lifted and lowered a box weighing 13 kg at a frequency of 10 lifts/min. The box (30 cm × 25 cm × 25.5 cm) was held by two cylindrical handles (28 mm diameter) extending 6 cm from either side of the box, at a height of 17 cm above its base (Fig. 1a). The box was lifted from a platform 15 cm above the floor to an upright standing position, then held before being lowered back onto the platform. Based on the anthropometric characteristics of the participant population and using the NIOSH revised lifting equation (Waters et al., 1993), the task was estimated to result in a lifting index (LI) = 2.1, which is above 1 and likely to pose an increased risk of lifting-related low back pain for a significant fraction of the workforce. This also represented a load acceptable to approximately 50% of the male population based on the psychophysical data of Snook and Ciriello (1991) A metronome operating at a frequency of 20 times per minute provided an audible cue of when to lift and lower the box, with participants commencing each lift and lower at the sound of the metronome. Participants continued lifting until they became fatigued and were unable to continue lifting, or had completed 20 min. Participants were verbally encouraged to maintain the required lifting rate, but could choose to stop at any time. They were not told how long the task would last, just to continue lifting for as long as possible.

When lifting and lowering the box, participants were required to maintain a fixed, symmetrical, foot position as close to the platform as possible, without touching it. Participants were instructed to maintain their hold on the box and lift to an upright standing position with their arms extended and relaxed, and the box resting against the thighs. Participants were reminded of these instructions throughout, but were not instructed on a lifting strategy.

Table 1
Mean (standard deviation) demographics for the two age groups.

	Younger group (n = 14)	Older group (n = 14)
Age (years)	24.4 (3.5)	47.2 (3.4)
Stature (m)	1.82 (0.08)	1.80 (0.10)
Body weight (kg)	81.0 (11.0)	83.6 (10.3)
Body Mass Index (BMI)	24.5 (2.8)	26.8 (2.3)

2.3. Kinematic and kinetic measures

A nine camera motion analysis system (Qualysis AB, Gothenburg, Sweden) sampling at 60 Hz recorded 3-dimensional kinematics. Lightweight (9 mm diameter), retro-reflective makers were attached to the skin of participants to track the position and movement of body segments (Fig. 1a). Markers attached to anatomical landmarks defined the dimension and axis of each body segment, whilst 'cluster' markers (Capozzo et al., 1997) on each segment were used as 'tracking' markers. Lumbar posture (lumbosacral (LS) angle) was measured using two pairs of markers mounted on lightweight rods and fixed to two small base plates attached to the skin superficial to the first lumbar (L1) spinous process and first sacral body (S1). LS angle was defined as the angle between two lines joining the centre of each pair of reflective markers (Mawston et al., 2007). Markers were attached to the skin using double-sided sticky tape and hypoallergenic tape. Three markers attached to the box track its movement.

An initial recording of the participant in a standing position was used as a reference posture ('static' trial) for subsequent biomechanical modelling. Markers attached to medial anatomical landmarks were removed during the task to avoid influencing the participant's lifting technique.

Prior to and immediately on completion of the repetitive lifting task, participants maximally flexed their lumbar spine whilst in a standing position (Dolan and Adams, 1998). Participants flexed as far as possible adopting slight knee flexion. This enabled subsequent dynamic measures of trunk flexion and LS angle to be expressed as a percentage of full flexion. Percentage flexion was expressed as:

$$\%\text{Flexion} = (\theta t - \theta s)/(\theta m - \theta s)$$

where:

θt dynamic angle during task
θs standing angle during 'static' trial
θm maximum flexion angle.

Participants stood on two AMTI (Advanced Mechanical Technology Inc., Watertown, USA) force platforms, one foot on each. These recorded 3D ground reaction forces and moments during the lifting task (sample rate = 1200 Hz). Kinematic and kinetic data were synchronised and recorded during two lifting cycles at the start and every minute thereafter.

2.4. Biomechanical model

An eight segment, rigid-link dynamic biomechanical model of the trunk, pelvis and right and left lower limbs (thigh, shank and foot) was constructed in Visual 3D (C-Motion Inc., Germantown, USA) (Montgomery et al., 2011) (Fig. 1b). Body segments were represented as geometric objects (Hanavan, 1964) and scaled according to each individual's anthropometrics. The mass, centre of mass and inertial properties of each segment were estimated using Dempster's data (Dempster, 1955). Raw kinematic and kinetic data were smoothed

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