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Relationship between leg and back strength with inter-joint coordination of females during lifting

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ABSTRACT

The role of strength and fatigue in the lifting technique is not very clear, especially with regards to inter-joint coordination. We examined the relationships between muscle strength and endurance with inter-joint coordination of the knee-hip (KH) and hip-back (HB) during a lifting task performed until exhaustion. Thirteen healthy females were recruited to participate in the study. Significant negative correlations were found between HB maximum relative phase angle and leg lifting strength ($r = -0.805$), knee extensor strength ($r = -0.705$), knee flexor strength ($r = -0.633$), back extensor strength ($r = -0.593$) and back flexor strength ($r = -0.596$). The greater the strength of these muscles, the more synchronized the hip-back inter-joint coordination. However, no significant relationships were found with endurance test performance. Moreover, although the lifting task induced muscle fatigue, there were no significant fatigue-induced changes in lifting coordination.

1. Introduction

Over the last three decades, the number of women in jobs with high physical workload has been increasing, as opposed to a decreasing number of men occupying these positions (Torgen and Kilbom, 2000). Manual material handling (MMH) is considered a high-risk job in the industry in relation to lower back injuries (LBI) (National Research Council, 2001) and in these jobs, women have been found to have higher rates of LBI than men (Kraus et al. 1997). A link has been suggested between LBI and the loads imposed by MMH (National Research Council, 2001). Differences in lifting techniques can lead to biomechanical changes that in turn may affect the risk of injury (Burgess-Limerick, 2003). However, most studies on lifting biomechanics have been conducted with male volunteers, and it is not clear if their results can be applicable to women (Lindbeck and Kjellberg, 2001).

Women in general are shorter than men (see Côté, 2012 for a review), and having shorter segments can influence the lifting technique (Chaffin et al., 2006). Women are also less strong than men, with women's lifting strength ranging between 40% and 73% of men's, meaning that for the same load women need to exert greater physical effort (Kumar 2004). In experimental studies when females have to lift the same load as males, lifting techniques differ substantially between sexes. For instance, Marras et al. (2003) indicated that females applied more hip flexion when they bent to reach the load, whereas males comparatively flexed their lumbar spine more. In a recent study (Plamondon et al., 2014b), expert male and experienced female MMH handlers performed the same lifting task using a 15 kg box. Both men and women adopted a squat oriented posture at the beginning of the lift. However, unlike expert males, women performed the lift with what appeared to be a sequential inter-joint coordination: they rapidly extended their knees and continued the lift in a way resembling a stoop, and thus were likely exposed to higher risk of injury (Plamondon et al., 2014b). The reasons for these differences are not fully understood but the authors suggested that sex/gender differences in lower limb and back strength may have played a role. However female workers with no experience and a longer, fatigue-inducing task might have produced different results.

Inter-joint coordination, a measure of the lifting technique used throughout the lifting motion, quantifies the relative movement between two adjacent joints (Burgess-Limerick et al., 1993; Scholz 1993). This measure has been previously shown to be influenced by task variables such as object mass, lifting height and load moment (Burgess-Limerick, 2003). When subjects adopted a

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posture at the start of the lift that is between a stoop and a squat, a distal to proximal sequence of movement was documented (Burgess-Limerick et al., 1995). With an increase in load weight, this pattern of movement becomes more sequential (Graham et al., 2013; Burgess-Limerick et al., 1995; Scholz et al., 1993; 1995; Schipplein et al., 1990). This sequential pattern can put the lumbar curvature close to its maximum range of motion which could be damaging to the ligaments, muscles and/or tendons (Maduri et al., 2008; Plamondon et al., 2014a). Novice workers are more prone to approach their limits of range of motion than the experienced lifters which could put them at higher risk of back injury, but can also increase their mechanical efficiency (Riley et al., 2015; Plamondon et al., 2014b; Maduri et al., 2008; Burgess-Limerick et al., 1995). Muscular strength could be a potential cause of the difference in the lifting technique observed between subjects (Puniello et al., 2001; Zhang and Buhr, 2002; Li and Zhang, 2009). In gender comparison studies when the load was scaled to the strength of the participants, there was no difference between males and females in their joint coordination pattern (Graham et al., 2013) which was not the case when it was not scaled (Plamondon et al., 2014b). In general, it is assumed that it is more beneficial to have a synchronous inter-joint coordination during lifting (Nimbarte et al., 2005; Graham et al., 2013; Plamondon et al., 2014b). Fatigue induced by a repetitive movement task can also lead to alterations in the lifting technique (Trafimow et al., 1993; Marras and Granata, 1997; van Dieën et al., 1998, Potvin, 2008) and in motor control and coordination patterns (Sparto et al., 1997; Côté et al., 2002; Fuller et al., 2011; Fedorowich et al., 2013). However the interaction between the lift's onset posture and the inter-joint coordination and their dual changes with fatigue is not fully understood.

Therefore, the aim of our study was to examine the effect of leg and back muscle strength and fatigue on inter–joint coordination among novice females. We hypothesized that females with greater leg and back strength and trunk endurance would display a more simultaneous inter-joint coordination during lifting and that inter-joint coordination would become more sequential with fatigue.

2. Methods

The study was divided into two experimental sessions separated by at least 72 h to avoid day-to-day fatigue or soreness effects. During the first session, physical capacity parameters were measured (strength and endurance) and the subjects were familiarized with the different experimental procedures. The second session specifically involved a task of fatigue induced by repetitive lifting of a 15 kg box.

2.1. Participants

A convenience sample of 13 healthy young females (mean age = 24.2 ± 3.4 years; mean height = 163.4 ± 5.5 cm; mean mass = 59 ± 8.4 kg) was recruited from institutional and social networks to participate in this study. Subjects were excluded if they had previous experience in MMH, had any lower back pain or injuries or musculoskeletal or cardiovascular impairment, or were diagnosed with a condition that could affect their performance of the experiment. The study was performed at the IRSST in Montreal, Quebec. At arrival, subjects provided written informed consent prior to participation by signing forms approved by the Research Ethics Board of CRIR of Greater Montreal.

2.2. Measuring systems

A photogrammetric measuring system, video cameras and an in-house-designed force platform (1.90 m × 1.30 m) were used to collect the kinematic and kinetic data necessary for the use of a dynamic 3D linked-segment model (details in Plamondon et al., 2014a, 2014b). EMG was recorded at 1024 Hz with pre-amplified bipolar electrodes (gain: 1000, model DE-2.3, Delsys, Boston, MA) placed bilaterally over the bellies of the biceps femoris (BF), vastus lateralis (VL), gluteus maximus (GM) and erector spinae (ES), following standard skin preparation (shaved, abraded, cleaned). A reference electrode was placed on the middle of the tibia. Heart rate (HR) was monitored with a Polar system (model RS800).

2.3. Session 1

On this first session the following physical tests were performed: general test of isometric maximal lifting strength (MLS), isometric maximal knee extension (MKE) and knee flexion (MKF) tests, maximal isometric back extension (MBE) and back flexion (MBF) tests and isometric endurance of trunk extensors (ETE) and flexors (ETF) (Fig. 1). The order of the tests was randomized. All maximal tests began with two warm up trials of 50% and 80% exertion, with 30 s rest in between. After 1 min of rest, three maximal attempts of each test were performed with 3 min of rest between each attempt and the highest result was taken. The subjects were instructed to gradually exert the force, and hold for 3 s when reaching their maximal output. The MLS test was performed while standing in half squat position of 120° of knee flexion (180° being the full extension) positioned to grasp a handle at knee height. The subject then exerted maximal extension force against a load cell fixed to the floor, maintaining a static position (Chaffin et al. 1978, 2006).

The MKE test was performed on a designated knee flexion/extension bench. The subject was seated, positioned with 90° flexion at the knees, hands holding the handles, and exerted a maximal extension force at the knees. The MKF test was performed with the subject lying prone on the designated bench, positioned with 90° of flexion at the knees. The subject then exerted a maximal flexion force at the knees. MBE and MBF tests were performed with the subject placed upright in a dynamometer and the pelvis stabilized (Larivière et al., 2001). The ETE test was also measured using the dynamometer with the same placement of the subject. The test consisted in exerting an isometric extension force equal to 50% of the previously measured maximum back extension strength to exhaustion (Reeves et al., 2006). ETF was measured using the V-sit test (McGill et al., 2010). The subject was positioned in a sit-up position, with her back rested on a jig at 60° from the floor. Both knees and hips were flexed 90°, the arms were folded across the chest with the hands placed on the opposite shoulders and the toes were stabilized by the experimenter. At the beginning, the jig was pulled 4 cm backwards and the subject tried to maintain the static posture until exhaustion, or until her back touched the jig (McGill et al., 2010).

Familiarization with lifting experimental procedures followed physical capacity tests. The subject was presented with a metronome, and was asked to lift a 5 kg box three times, and a 15 kg box three times. During the familiarization session, no lifting technique was ever demonstrated to the participants and no comments were given about the technique they used.

2.4. Session 2

On this second session, the lifting task was performed by the participants. The lifting task consisted in lifting a 15-kg box with no handles (26 cm deep × 35 cm wide × 32 cm high) using a custom-made two pallet-lifting device (Fig. 2). The bottom height of the box from the force platform was 16.5 cm, and this height from the ground was kept constant for all subjects. Subjects had to lift the