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External loading alters trunk kinematics and lower extremity muscle activity in a distribution-specific manner during sitting and rising from a chair

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ABSTRACT

Background: Excess body mass alters gait biomechanics in a distribution-specific manner. The effects of adding mass centrally or peripherally on biomechanics during sitting and rising from a chair are unknown.
Methods: Motion analysis and lower extremity EMG were measured for fifteen healthy, normal weight subjects during sit-to-stand (SitTS) and stand-to-sit (StandTS) from a chair under unloaded (UN), centrally loaded (CL), and peripherally loaded (PL) conditions.
Results: Compared to UN, PL significantly increased support width (SitTS and StandTS), increased peak trunk flexion velocity (SitTS), and trended to increase peak trunk flexion angle (SitTS). During StandTS, CL significantly reduced peak trunk flexion compared to UN and PL. EMG activity of the semitendinosus, vastus lateralis and/or medialis was significantly increased in CL compared to UN during SitTS and StandTS.
Conclusions: Adding mass centrally or peripherally induces contrasting biomechanical strategies to successfully sit or rise from a chair. CL limits trunk flexion and increases knee extensor muscle activity whereas; PL increases support width and trunk flexion, thus preventing increased EMG activity.

1. Background

Excess body mass is associated with increased risk of mobility disabilities (Lang et al., 2008; Sternfeld et al., 2002; Wong et al., 2012; Zoico et al., 2004), musculoskeletal injury (Garzillo and Garzillo, 1993), and lower extremity joint osteoarthritis (Harding et al., 2014; Messier et al., 2014), potentially due to altered biomechanics when performing a variety of activities daily living (ADLs) (Schmid et al., 2013a; Sternfeld et al., 2002). Typically, biomechanical adaptations have been reported in severely obese individuals, but not those who are overweight or moderately obese (Schmid et al., 2013a; Sternfeld et al., 2002), suggesting that moderate increases in body mass may not negatively affect biomechanics. Due to the multifactorial nature of obesity, it is difficult to determine how increases in body mass *per se* affect kinematics and muscle recruitment during ADLs.

Excess body mass is typically accumulated as adipose tissue in either the abdominal (central) or upper thigh (peripheral) regions (Ley and Lees, 1992; Mastaglia et al., 2012; Samsell et al., 2014). The specific distribution of excess body mass may influence center of mass, and thus alter biomechanics, skeletal muscle activity, and workload (Abe et al., 2004). Indeed, excess mass affects gait in a distribution-specific manner (Abe et al., 2004; Browning et al., 2007; Messier et al., 2014; Sternfeld et al., 2002; Westlake et al., 2013) suggesting that central and peripheral distribution of mass may increase the risk of lower extremity injury and physical disability via distinct biomechanical mechanisms. Few studies have examined how distribution of mass affects kinematics during other ADLs such as sit-to-stand (SitTS) and stand to sit (StandTS).

SitTS and StandTS are ADLs which indicate a level of functional independence (Gilleard et al., 2008, 2002; Sibella et al., 2003). SitTS is initiated by trunk flexion to gain sufficient momentum required to complete the task (Janssen et al., 2002; Papa and Cappozzo,

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2000). Savelberg et al. (2007) demonstrated that increasing mass of the trunk by 45% of total body mass significantly decreased trunk flexion angle during SitTS which is comparable to findings from severely obese subjects (Galli et al., 2000; Schmid et al., 2013a; Sibella et al., 2003). These studies suggest that increases in trunk mass result in decreased trunk flexion during SitTS. However, these studies did not account for differences in body mass distribution.

In addition to kinematics, lower extremity muscle activation – particularly of the knee extensors - is an important determinant of SitTS performance (Crockett et al., 2013; Kotake et al., 1993). Compared to normal weight individuals, knee extensor EMG activity is greater in obese adults during SitTS (Sibella et al., 2003). Since a hallmark feature of obesity is excess body mass, these data suggest that excess body mass increases knee extensor activation during this task. Indeed, even moderate gains in trunk mass are sufficient to increase knee extensor muscle activation during SitTS (Savelberg et al., 2007). Interestingly, placing external loads of 45% total body mass on the trunk also increases muscle activation of the knee flexors and plantarflexors during SitTS (Savelberg et al., 2007). Placing loads further from the center of mass increases torque at lower extremity joints and likely requires increased skeletal muscle force (Abe et al., 2004). Therefore, peripheral addition of mass may elicit greater increases in knee extensor, knee flexor, and/or plantarflexor activation during SitTS and StandTS compared to when the load is added centrally.

The purpose of this study was to determine the effects of excess mass, distributed centrally or peripherally, *per se* on trunk kinematics and lower extremity skeletal muscle activity during SitTS and StandTS. In order to accomplish this, normal weight men and women performed SitTS and StandTS under unloaded, centrally loaded, and peripherally loaded conditions. We hypothesized that: (1) central, but not peripheral, loading would decrease trunk flexion and (2) knee extensor, but not knee flexor or plantarflexor, EMG activity would increase with loading and that this effect would be greater during the peripherally loaded condition.

2. Materials and methods

2.1. Subjects

Fifteen healthy, normal weight subjects (five male, ten female), ages 19-33y, volunteered to participate in this study. Subjects were recreationally active and weight stable for the previous 6 months.

Anthropometric data (height, weight, and waist and hip circumferences) from each subject were collected. Waist circumference was taken at the visually narrowest point near the umbilicus and hip circumference was at the visually maximal circumference of the subject's gluteus muscles using a spring-loaded flexible tape measure.

2.2. Load carriage and distribution

In order to determine how central and peripheral loading affect kinematics and lower extremity muscle activation, subjects carried external loads equivalent to a 5 kg/m^2 BMI increase which was the heaviest load subjects could carry while limiting simulated weight gain to BMI to <30 kg/m^2. For central loading, 100% of the external load was placed in an adjustable weighted vest. For peripheral loading, approximately 50% of the external load was carried in the adjustable weight vest and approximately 25% to adjustable neoprene compression sleeves on each thigh. This distribution was selected based on previously published literature indicating that 50–60% of adipose tissue is distributed centrally and 40–50% of adipose tissue is distributed to the thigh region (Ley and Lees, 1992; Mastaglia et al., 2012; Samsell et al., 2014; Sibella et al., 2003). Each subject completed the tasks under unloaded (UN), centrally loaded (CL), and peripherally loaded (PL) conditions in randomized order.

2.3. SitTS and StandTS tests

Subjects completed the SitTS and StandTS tasks from a 52 cm high chair. For ease of kinematic data collection and to standardize body position, subjects crossed their arms over their chest during data collection. The mean of three trials for each activity was reported. During data collection, subjects did not use the arm rails, and both feet remained in contact with the floor for the duration of the trial. Foot position was standardized in the sagittal plane (heels in line with front of chair) to eliminate excessive knee flexion. SitTS and StandTS were performed independently (i.e. no continuous motion between the activities). Subjects were given up to 5-min of seated rest between trials and between load conditions.

2.4. Motion analysis

Fifty-six small retro-reflective markers were attached to the subject's skin to identify anatomical landmarks of the lower extremity and trunk (anterior/posterior shoulders, acromial angles, jugular notch, T12, anterior/posterior superior iliac spines, iliac crests, L5/S1, medial/lateral femoral condyles, medial/lateral malleoli, proximal/distal/lateral heels, 1st and 5th metatarsal heads, and toes. Soft shell marker clusters were placed on the thighs and shanks. Anatomical/joint markers were used for a static calibration trial and 34 tracking markers remained on the subject's during testing. Ten high speed cameras (Motion Analysis Corp, Santa Rosa, CA) were used to capture retro-reflective marker coordinate data throughout testing (200 Hz).

2.5. Surface electromyography

Subjects were prepared for surface electromyography (sEMG) of medial gastrocnemius (MG), semitendinosus (ST), vastus lateralis (VL), and vastus medialis (VM) of the self-reported dominant leg following SENIAM guidelines (Davidson et al., 2013; Devroey et al., 2007). Electrodes with a bi-polar Ag surface (Delsys Inc., Boston, MA) were placed at the distal third of each muscle parallel to fiber orientation. Skin was shaved, abraded, and cleaned with an alcohol swab to ensure direct contact. An additional grounding electrode was secured on the subject's ipsilateral hand. Baseline muscle activity was recorded in a supine position for 2 min followed by two manually resisted reference contractions for each muscle group using manual resistance. Muscle activity was detected (1000 Hz) with DE-2.1 single differential sEMG sensor and amplified by a Bagnoli™ 16-channel system (Delsys Inc., Boston, MA). Two male outliers were excluded from EMG data analyses due to grossly elevated VL and ST EMG activity (>2 SD above the mean) during testing. Therefore, all EMG data are reported with N = 13.

2.6. Data processing and analysis

Data were processed using Cortex 5.5 (Motion Analysis Corporation, Santa Rosa, CA). EMG and motion analysis were completed using Visual 3D (C-Motion Inc., Germantown, MD). The arithmetic mean of three trials under each load condition was reported.

Kinematic data were filtered using a 4th order Butterworth low-pass filter with a cut-off of 8 Hz. The cycle was initiated when hip flexion angle exceeded 5 standard deviations from the initial hip angle for 10 frames, and termination was when the subject's hip angle dropped by 5 standard deviations from the final hip extension angle (SitTS) and vice versa for StandTS. The time