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Kinematics and knee muscle activation during sit-to-stand movement in women with knee osteoarthritis

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ABSTRACT

Backround: The purpose of this study was to compare joint kinematics, knee and trunk muscle activation and co-activation patterns during a sit-to-stand movement in women with knee osteoarthritis and age-matched controls.
Methods: Eleven women with knee osteoarthritis (mean and standard deviation, age: 66.90, 4.51 years, height: 1.63, 0.02 m, mass: 77.63, 5.4 kg) and eleven healthy women (mean and standard deviation, age: 61.90, 3.12 years, height: 1.63 m, 0.03, mass: 78.30, 4.91 kg) performed a Sit to Stand movement at a self-selected slow, normal and fast speed. Three-dimensional joint kinematics of the lower limb, vertical ground reaction forces and electromyographic activity of the biceps femoris vastus lateralis and erectus spinae were recorded bilaterally.
Findings: A two-way ANOVA showed that the osteoarhtitis group performed the sit to stand task using a smaller knee and hip range of motion compared with the control group while no differences in temporal kinematics and ground reaction force-related parameters were observed. In addition, women with osteoarhtritis displayed significantly lower vastus lateralis coupled with a higher biceps feomoris electromyographic activity and higher agonist–antagonist co-contraction and co-activation than asymptomatic women. The activation of erectus spinae was not different between groups.
Interpretation: Results indicate that patients with moderate knee osteoarthritis rise from the chair using greater knee muscle co-contraction, earlier and greater activation of the hamstrings which results in reduced hip and knee range of motion. This may be a way to overcome the pain and potential muscle atrophy of knee extensor muscles without compromising overall task duration.

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1. Introduction

A growing number of studies have reported altered neuromuscular activation and movement patterns during functional activities in individuals with knee osteoarthritis (OA) (Bennell et al., 2008; Bennell et al., 2013; Childs et al., 2004; Hortobagyi et al., 2005; Hubley-Kozey et al., 2009; Lewek et al., 2004; Patsika et al., 2011; Slemenda et al., 1997). These alterations are linked with typical OA symptoms such as quadriceps muscle weakness (Bennell et al., 2008; Bennell et al., 2013) and pain (Slemenda et al., 1997) and may signify impairments in performance of daily activities with negative implications for quality of life in these individuals.

Research studies have shown that individuals with knee OA display different movement strategies when performing a STS task than asymptomatic individuals (Pai et al., 1994; Segal et al., 2013; Turcot et al., 2012a). Particularly, OA patients perform the STS task at a slower speed (Patsika et al., 2011), a lower knee range of motion, extension (Pai et al., 1994) and flexion torque (Turcot et al., 2012b), a higher hip extension torque (Pai et al., 1994) and a more posterior position of the center of pressure (Patsika et al., 2011) than asymptomatic controls. Furthermore, there is evidence that OA affects the activity of major trunk extensors muscles. Turcot et al. (2012a, 2012b) reported that patients with knee OA showed a higher maximal trunk flexion and a higher lateral trunk lean on the contralateral side when compared with the control group, making the trunk a major contributor to STS task. All these factors imply that pathological or pain-related constraints set by knee OA on the musculoskeletal system, may lead to altered intersegmental coordination solutions to accomplish the same overall task goal. Yet, the redundancy of the degrees of freedom available in the human motor system allows for the development of new movement affordances ensuring effective interaction with the physical environment for the successful accomplishment of the tasks of daily living.

Altered neuromuscular patterns are mostly translated into different muscle co-contraction patterns while individuals perform a given movement (Mills et al., 2013). Co-contraction is defined as the simultaneous activity of agonist and antagonist muscles surrounding a joint (Kellis, 1998). Higher co-contraction may be linked with higher joint

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stiffness (Baratta et al., 1988; De Luca and Mambrito, 1987; Solomonow et al., 1987) and altered control of force transfer from the hip to the knee via the work of the bi-articular components of the hamstrings and quadriceps (Roebroeck et al., 1994). Evidence indicates elevated quadriceps and hamstrings co-contraction in OA patients during isolated strength exercises (Kellis et al., 2013), stance phase of walking (Childs et al., 2004; Hortobagyi et al., 2005) or stand-to-sit (STS) movement (Patsika et al., 2011). Particularly, research studies have found that individuals with knee OA display a high vastus lateralis (VL) to biceps femoris (BF) activation ratio (lateral muscle co-contraction) (Childs et al., 2004; Hubley-Kozey et al., 2009; Lewek et al., 2004). In a systematic review (Mills et al., 2013), co-contraction was considered as "a prevalent muscle adaptation" when the knee is fully loaded, in order to protect the medial knee joint from excessive loading. In a previous study, Patsika et al. (2011) found similar activity of the vastii muscles but a higher antagonist BF activation during the STS task in women with knee OA compared with controls. However, the co-contraction patterns during the STS movement have not been thoroughly investigated.

Altered muscle activation patterns when performing a movement are not only associated with the concurrent changes in amplitude but also on the timing of muscle activity. Studies have shown that individuals with knee OA demonstrated 1.5 times longer vastus lateralis (VL), medial hamstrings, tibialis anterior, medial gastrocnemius and rectus femoris activation during level and inclined walking (Patsika et al., 2011; Rutherford et al., 2011) or toe out walking (Rutherford et al., 2011) than that observed in asymptomatic individuals. To our knowledge, relative duration of muscle activation or more specifically temporal co-activation of agonist–antagonist muscle pairs at the knee when performing a STS task by people with OA has not been previously examined. Examination of the relative onset of activation of several muscles that are activated during a task may provide additional information on co-ordination patterns that accompany the altered movement strategies adopted by people with knee OA.

Performance of the STS task may also depend on the speed of execution of this task (Janssen et al., 2002; Pai et al., 1994). An increase of speed leads to a greater hip flexion torque and a lower knee extension and ankle dorsiflexion moments during STS (Pai et al., 1994). Vander Linden et al. (1994) reported that when individuals were asked to stand as fast as possible, muscle onsets and movement phases were shortened. Elderly individuals generally show a slower speed of the STS task than younger ones (Mourey et al., 2000), but they show less hip flexion when performing the STS movement faster (Papa and Cappozzo, 1999). Since older individuals with knee OA perform STS even slower than asymptomatic ones (Patsika et al., 2011), then examining the effects of speed on muscle activation and joint kinematics during the STS task is worthwhile.

The purpose of this study was to determine whether women with knee osteoarthritis (OA) and asymptomatic controls (CON) show different movement, trunk and knee muscle activation and co-contraction patterns when rising from a chair at different self-selected speeds. Movement kinematics and muscle activation were examined using both amplitude and time domain measures.

2. Method

2.1. Participants

Eleven women with knee OA (mean and standard deviation, age: 66.90, 4.51 yr, height: 1.63, 0.02 m, mass: 77.63, 5.4 kg) and eleven controls (mean and standard deviation, age: 61.90, 3.12 yr, height: 1.63, 0.03, mass: 78.30, 4.91 kg) volunteered to participate in this study. A power analysis performed prior to experimentation indicated that a minimum number of ten participants per group was sufficient to ensure statistical power considering an effect size of 0.75, a minimum power of 0.80, and a p value of 0.05. Women with knee OA displayed grade II or III unilateral OA at the medial tibiofemoral compartment of right knee joint, as evidenced by radiographic assessment using Kellgren and Lawrence criteria (Kellgren and Lawrence, 1957). All women completed the Western Ontario and McMaster University Index (WOMAC) as an indicator of self-reported pain, stiffness and function (Bellamy et al., 1988). Healthy women had no musculoskeletal or neuromuscular pain or any injury of the knee and hip joint. All participants were regularly active, but they didnot participate in systematic training programs. They werefully informed on the purpose of the study and signed a written consent form, in order to participate in this study. The study was approved by University Ethnics Committee.

2.2. Instrumentation

Two adjusted force plates (Balance Plate 6501, Bertec Corp., Columbus, USA) with a sampling frequency of 100 Hz, were used to record the vertical ground reaction forces during performance of the STS task. A 10 camera Vicon system (Bonita 3, Nexus Vicon, Oxford, UK, sampling, 100 Hz) was used to record joint kinematics for the lower body. In addition an 8-channel wireless EMG system (Telemyo DTS, Noraxon USA Inc), sampling at 1000 Hz, was used to record the bilateral EMG activity of selected knee muscles. The ground reaction forces, EMG signals and markers 3D position coordinates were synchronously sampled using the Vicon system that was connected to an A/D card (MX Giganet Oxford, UK). All signals were stored and further processed using the NEXUS (version 1.8.3) software and custom analysis software, programmed in Matlab (Version 7.7, MathWorksInc, USA).

2.3. Procedure and task

EMG activity of selected knee muscles was collected using bipolar active surface electrodes (Ag/AgCl electrodes, EL504, BIOPAC Systems). The skin was shaved with alcohol wipes to remove any dead cells. The electrodes were placed according to S.E.N.I.A.M. recommendations (Hermens et al., 2000). Particularly, two electrodes were placed over the long head of the Biceps Femoris (BF), half way on the line between the ischial tuberosity and the head of the fibula, over the distal position of the vastus lateralis (VL) muscle, 10 cm above and medially from the superior border of patella of both legs. Further, an additional pair of electrodes was placed on the right Erectus Spinae muscle, approximately 3 cm laterally from the L1 spinal process. The EMG signals were amplified (gain 1000, input impedance 10 MΩ, CMRR 130 dB) and filtered using a band-pass filter (20 Hz–450 Hz) before stored for further digital processing.

Also, for the purpose of the present experiment, 16 passive reflective markers were attached to specific anthropometric landmarks dictated by the analysis software (NEXUS 1.8.3.), for the calculation of the segment and joint angles from the markers 3D position coordinates using the Plug-in-Gait model. A static trial was captured in order to calculate the anatomical angles from the marker coordinates using Vicon's Plug In Gait model. The measurement volume was approximately $3.5 \times 3.5 \times 3$ m and the mean image error for all cameras was 0.10 mm (st. deviation = 0.01).

The experimental task required rising from a chair, at three different self selected speeds. The chair had no arms and its height was adjusted to the participant's height so as to ensure a right knee angle at the sitting position. The feet were placed parallel to each other, one over each force platform while the arms were stabilized on the waist. From this position, participants were asked to rise from the chair without using their arms. After three practice trials, the participants performed three trials at their self selected normal speed (Gross et al., 1998). They were then asked to perform additional three trials "faster" and then "slower" than their normal speed. Appropriate rest interval was provided between trials. The sequence of trials was randomized across participants.

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