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Toe-in and toe-out walking require different lower limb neuromuscular patterns in people with knee osteoarthritis

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ABSTRACT

Toe-in and toe-out gait modification has received attention lately as a promising treatment for knee osteoarthritis due to its potential to improve knee joint loading and pain. However, the neuromuscular patterns associated with these walking styles are not well known, a factor that may influence knee joint load itself. Our aim was to conduct a thorough examination of the neuromuscular patterns associated with toe-in and toe-out walking in people with knee osteoarthritis. Fifteen participants were instructed to walk in four different foot rotations: 10° toe-in, 0°, as well as 10° and 20° toe-out. Nine surface electrodes were placed over lower extremity muscles and a variety of muscle activation parameters were examined. Peak and average medial hamstrings muscle activation was increased ($p = 0.001$, $p < 0.001$) during toe-in walking compared to toe-out walking. As well, average lateral gastrocnemius muscle activation was higher ($p = 0.001$) during toe-in walking compared to 20° toe-out. Medial thigh muscle co-contraction was higher ($p = 0.003$) during toe-in walking compared to all other conditions, and medial to lateral gastrocnemius activation ratio was lower ($p = 0.032$) during toe-in walking. These findings suggest potential overall increased joint loading with toe-in walking as a result of muscle co-contraction. Long-term assessment of these strategies is warranted.

1. Introduction

Osteoarthritis (OA) is a chronic disease which can result in substantial disability and pain (Salaffi et al., 2005). The knee is often afflicted by the disease and a variety of risk factors are associated with the development and progression of knee OA. Two important and modifiable risk factors are excessive joint load and neuromuscular dysfunction (Bennell et al., 2011; Miyazaki et al., 2002; Oiestad et al., 2015). Traditional treatment approaches (joint replacement and pharmacology) are not intended to address knee joint load or neuromuscular factors, and are associated with a high risk of side effects. Therefore, an urgent need exists for alternative treatments to manage the disease by addressing these factors. This is becoming more important as recent investigations have shown a rise in symptomatic knee OA, particularly in younger age categories (Deshpande et al., 2016). This will lead to individuals living longer with the disease, thereby increasing strain on the health care system.

Gait modification is a viable conservative strategy, encompassing a variety of alterations to one's gait (Richards et al., 2017; Simic et al., 2011). The objectives of these gait modifications are to redistribute knee load, primarily via reductions in the external knee adduction moment (KAM), and to improve symptoms such as pain. The KAM is an accepted proxy of knee joint load distribution, and is an outcome measure linked to disease progression (Bennell et al., 2011; Hatfield et al., 2016; Miyazaki et al., 2002).

Toe-in (TI) and toe-out (TO) walking, in particular, have gained attention in recent years due to their potential to improve knee load and symptoms. A single-session study observed that TI and TO walking of varying degrees has the potential to reduce KAM magnitudes in people with knee OA (Simic et al., 2013). Two clinical trials in knee OA populations expanded these findings by reporting reductions in early stance peak KAM of 20% (Shull et al., 2013) and late stance peak KAM of 10.5% (Hunt and Takacs, 2014), and self-reported pain by 29% and 28.4% during TI and TO walking, respectively. These studies highlight the effectiveness of TI and TO walking as a conservative treatment strategy for knee OA; however little is known regarding how altering gait in this manner may affect neuromuscular patterns of the lower extremities or the mechanics of joints other than the knee.

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Neuromuscular patterns may have both beneficial and detrimental effects on knee joint mechanics; therefore, advancing our current understanding of how TI and TO walking may change these patterns is important prior to clinical implementation.

During natural walking, individuals with knee OA typically exhibit greater muscle activation and co-contraction of the lateral thigh musculature, and greater muscle activation duration of the periarticular knee muscles (Childs et al., 2004; Heiden et al., 2009; Hubley-Kozey et al., 2006; Hubley-Kozey et al., 2009; Lynn and Costigan, 2008). The effect of gait modification on the neuromuscular function of young healthy participants and people with knee OA is less known. Individualized TI and TO walking modification elicited immediate quadriceps and hamstrings co-contraction increases in healthy adults (Uhlrich et al., 2018). In those with knee OA, toe-out walking has been shown to increase lateral hamstrings activation relative to the medial hamstrings, (Lynn and Costigan, 2008). Additionally, a delay in gastrocnemii activation onset, and an increase in quadriceps activation (both duration and magnitude), have been observed during TO walking compared to natural walking (Rutherford et al., 2010). Taken together these findings suggest a possible magnification of the already abnormal neuromuscular characteristics of individuals with knee OA, compared to healthy or asymptomatic individuals, when performing toe-in or toe-out walking.

The present study compared the neuromuscular patterns, specifically: average muscle activity, peak muscle activity and co-contraction indices of the thigh muscles and medial to lateral thigh muscle activation ratio during four commonly researched foot rotation conditions: 10° TI (TI10), 0° (ZR), 10° TO (TO10) and 20° TO (TO20) in people with knee OA. The purpose was to examine the neuromuscular patterns elicited during walking with these foot rotation magnitudes. We hypothesized that TO walking would increase lateral muscle activation and co-contraction while TI walking would increase medial muscle activation and co-contraction.

2. Methods

2.1. Participants

Fifteen individuals diagnosed with medial tibiofemoral OA (6 male, 9 female; mean (standard deviation (SD)) age = 67.9 (9.4) years; height = 1.68 (0.11) m; body mass = 75.6 (15.0) kg; n = 7 mild OA; n = 8 moderate OA) were recruited from the community via print media and existing laboratory databases. Individuals participated in a study examining overall lower limb biomechanical changes (kinematics, kinetics and electromyography) during different foot rotation-based gait patterns. Data reported in this study relate to electromyographic data only, except for foot rotation angle. Inclusion criteria included: radiographic medial compartment knee OA (Kellgren and Lawrence (KL) (Kellgren and Lawrence, 1957) grade ≥ 2 – mild OA severity = KL grade 2; moderate OA severity = KL grade 3); 50 years of age or greater; knee pain on most days of the previous month; and the ability to walk on a treadmill unaided. Exclusion criteria included: lateral tibiofemoral OA > medial tibiofemoral OA; foot rotation during natural walking greater than ± 15°; previous total knee arthroplasty (at any time) or arthroscopic knee surgery (within the previous six months); recent use of corticosteroids; and self-reported foot pain. The study was approved by the institutional Clinical Research Ethics Board, and all participants provided written informed consent prior to inclusion in the study.

2.2. Data collection

Participants attended a single testing session. Descriptive data including age, height and body mass were collected prior to gait analysis. Gait analysis consisted of three-dimensional motion analysis and surface electromyography during self-selected barefoot over-ground walking under four randomly-ordered foot rotation conditions: TI10, ZR, TO10, and TO20. The study limb was selected as the limb with knee OA (unilateral cases) or the most symptomatic limb (bilateral cases).

As part of the overall study, forty-seven passive retroreflective markers were affixed bilaterally to the skin over various anatomical landmarks, similar to a previous marker set (Hatfield et al., 2016). For the purposes of the present study, foot rotation was defined as the angle of the long axis of the foot segment (a line bisecting the second metatarsal marker and the calcaneal marker) relative to the forward axis (direction of walking) of the global coordinate system. The second metatarsal marker was placed on the distal head while the calcaneal marker was centred on the posterior aspect of the calcaneus at the same vertical height as the second metatarsal marker.

Muscle activity was recorded (2000 Hz) using wireless bipolar surface EMG sensors (Delsys Inc, Natick, MA) placed over the muscle bellies and in line with the muscle fibres of nine lower extremity muscles (Fig. 1): medial gastrocnemius (MG), lateral gastrocnemius (LG), soleus (SO), tibialis anterior (TA), peroneus longus (PL), vastus medialis (VM), vastus lateralis (VL), lateral hamstrings (LH), and medial hamstrings (MH). Electrodes (Ag, four contact locations per electrode (rectangular contact dimension 1 × 5 mm) were placed according to international guidelines (Hermens et al., 2000) and were validated by muscle palpation and targeted isometric contractions by the lead author (JMC). The skin was prepared prior to electrode placement by shaving the area and cleaning with a 70% alcohol wipe. Signals were recorded using a Trigno™ Wireless System (Delsys Inc, Natick, MA), inter-electrode distance 10 mm, bandpass 20–450 Hz, input impedance > 10Ω, input

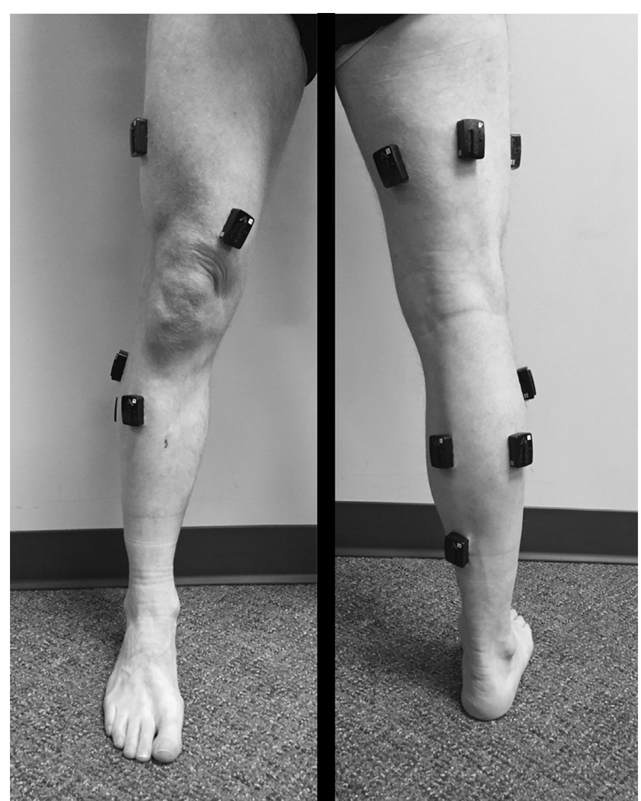

Fig. 1. Anterior and posterior view of lower extremity, indicating electrode placements.