Clinical Biomechanics 45 (2017) 25–31

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

# Dual-belt treadmill familiarization: Implications for knee function in moderate knee osteoarthritis compared to asymptomatic controls

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A R T I C L E I N F O

*Keywords:*
Knee osteoarthritis
Gait analysis
Biomechanics
Electromyography
Treadmill walking

A B S T R A C T

*Background:* Effect of treadmill familiarization on knee function in osteoarthritis is not clear. Purpose was to determine whether spatiotemporal characteristics, knee joint biomechanics and muscle activation patterns change as individuals with and without medial compartment knee osteoarthritis familiarize to dual-belt treadmill walking over 6 min.

*Methods:* 20 individuals with knee osteoarthritis and 20 asymptomatic controls walked at a self-selected speed. Spatiotemporal characteristics, sagittal plane joint motions, sagittal and frontal plane moments and knee joint muscle activation patterns, amplitude normalized to maximum isometric contractions were analyzed. Discrete measures were extracted from each biomechanical waveform and principal component analysis was used to determine knee joint muscle activation patterns. Statistical significance was determined using Analysis of Variance models (alpha = 0.05).

*Findings:* Spatiotemporal gait characteristics, knee motion and moment differences were found between groups however no group by time interactions existed and no changes in these variables were found over 6 min of walking. Group differences in muscle activation patterns were found in all muscle activations. Muscle activation amplitude and patterns at minute 5 and 6 were generally lower, less prolonged and more dynamic when compared to minute 1 and 3.

*Interpretation:* Individuals with and without medial compartment knee osteoarthritis familiarized to treadmill walking in a similar manner. Minimal changes to knee biomechanics were found during treadmill familiarization. Five to six minutes of familiarization should be considered for surface electromyography in these populations.

## 1. Introduction

Knee osteoarthritis (OA) has negative implications for walking ability and is a leading cause of chronic morbidity worldwide (Turkiewicz et al., 2014). Gait researchers have utilized knee mechanics and muscle activations, recorded during walking, to understand the implications of OA on dynamic joint function. Reduced sagittal plane range of motion, a less dynamic flexion-extension moment, and altered quadriceps and hamstring activation are commonly found in those with symptomatic OA in comparison to asymptomatic control groups using gait analysis methodology (Astephen et al., 2008; Childs et al., 2004; Hubley-Kozey et al., 2006). These altered pathomechanics at the knee joint have been discussed as a central factor in the development and progression of OA (Andriacchi and Favre, 2014).

From a mechanical perspective, sagittal and frontal plane knee moments in individuals with knee OA have been studied and implicated in joint loading and dynamic stiffness during gait (Creaby et al., 2013; Dixon et al., 2010; Hatfield et al., 2015) and have implications for studying mechanics of disease progression (Hatfield et al., 2015; Manal et al., 2015) and cartilage loss (Chehab et al., 2014). Generally, the knee is less dynamic during stance evidenced through reduced sagittal plane motions and moments and altered medial/lateral compartment loading distribution, measured by the knee adduction moment (KAM) (Astephen et al., 2008). While biomechanics have been widely studied in knee OA gait, in the past decade, there has been an increasing interest in quadriceps, hamstring and gastrocnemii muscle activation. Amplitude levels and patterns of activity have been studied, implicated in knee stability and joint function during walking (Childs et al., 2004; Rudolph et al., 2007; Rutherford et al., 2013) and may have implications for long-term knee cartilage volume (Hodges et al., 2016). Muscle

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http://dx.doi.org/10.1016/j.clinbiomech.2017.04.006
Received 7 July 2016; Accepted 14 April 2017

activation patterns are altered with degree of knee OA severity (Rutherford et al., 2013), where depending on the muscle, amplitudes could be elevated, less dynamic or more prolonged and thought to reflect knee joint demands during gait. Together, findings of a less dynamic knee with greater muscular co-activity suggest that dynamic knee function is altered as a result of OA and has implication for gait pathomechanics.

To date, knee OA gait pathomechanics have been understood using a relatively brief examination (3–10 strides) of over ground walking which could be completed with less than 2 min of total walking exposure. Studies have not routinely reported familiarization trials before measurements are taken. For gait assessments using a treadmill, familiarization periods are recommended however implications for familiarization on understanding OA gait mechanics and muscle activation patterns are not clear. For healthy young adults, 5 min of familiarization has been recommended for dual-belt treadmill walking (Zeni and Higginson, 2010) and for older adults on a single belt treadmill, 14 min (Wass et al., 2005). To date, previous work in healthy individuals has not focused on joint moments and muscle activations studied in knee OA gait. Currently, we have little understanding of how knee biomechanics (motion and moments) and muscle activation patterns change in a moderate knee OA population as individuals familiarize to a dual-belt instrumented treadmill and whether these outcomes have implications for differentiating from an asymptomatic group.

The objective of this study was to determine whether spatiotemporal characteristics, sagittal and frontal plane knee moments, sagittal plane motion and knee muscle activation patterns differ between individuals with moderate medial compartment knee OA (MOA) and an asymptomatic (ASYM) group as they walk on a dual-belt instrumented treadmill for one, three, five and 6 min. It was hypothesized that ASYM individuals will familiarize to treadmill walking quicker, showing fewer time differences, than individuals with knee OA however both groups will show minimal differences between minute 5 and 6 for all variables. As individuals familiarize, it was hypothesized that, step width will reduce, knee motion and sagittal plane moments will become more dynamic during stance, no changes will occur in the frontal plane moments and muscle activation will reduce and become less prolonged. Finally, it was hypothesized that group differences will be found between ASYM and MOA groups at minute 6. Specifically, the MOA group will demonstrate reduced sagittal plane knee motion and knee moments, larger knee adduction moments and altered quadriceps and hamstring activation patterns compared to the ASYM group.

## 2. Methods

### 2.1. Participants

Twenty participants were recruited for each group. Participants with unilateral symptomatic MOA were recruited after consultation with an orthopaedic surgeon and excluded if they were candidates for total knee replacement. OA was determined using the American College of Rheumatology guidelines (Altman, 1991). All standard anterior-posterior radiographs were scored by one orthopaedic surgeon (IW), who was blinded to participant identification and gait outcomes, using the Kellgren-Lawrence ordinal radiographic scale (Kellgren and Lawrence, 1957). Additionally, a previously employed functional classification was used to determine moderate severity (Hubley-Kozey et al., 2006). The ASYM group was considered a sample of convenience, recruited through university and local community advertisements. All participants were required to have no fracture or injury other than a sprain or strain and be able to walk independently with no neurological or cardiovascular disorder that would impair walking ability. The protocol was approved by the local institutional ethics review committee.

### 2.2. Gait analysis

All MOA participants were asked to complete the Knee Osteoarthritis Outcome Score (KOOS), which also included the Western Ontario McMaster Osteoarthritis Index (WOMAC) sub-scores. Participants then changed into tight fitting shorts, a T-shirt, removed their footwear and height and mass were recorded. All individuals completed at least 10 walking trials at a self-selected speed across the GaitRITE™ instrumented walkway (CIR Systems, USA). Five trials were randomly recorded to determine average walking speed.

Participants were prepared for surface electromyography (EMG); skin was lightly shaved and cleaned with 70% alcohol wipes. Consistent with guidelines (Hermens et al., 2000) and standard procedures (Surface EMG for the Non-Invasive Assessment of Muscles), Ag/AgCl surface electrodes (10 mm diameter, 30 mm inter-electrode distance, Red Dot, 3M Health Care, USA) were placed bilaterally in a bipolar configuration over vastus lateralis (VL), medialis (VM) and rectus femoris (RF) and both medial (MH) and lateral (LH) hamstrings, medial (MG) and lateral (LG) gastrocnemius. Surface EMG was recorded with two AMT-8™ 8-channel Bortec systems (Bortec Inc., Canada) at 2000 Hz using Qualisys Track Manager 2.10 (Qualisys, Sweden).

Rigid plastic plates containing four retro-reflective spheres were placed on the trunk, pelvis, lateral femur, lateral tibia, foot and previously defined anatomical landmarks using velcro straps and secured with adhesive tape (Dunphy et al., 2016). Retro-reflective spheres were tracked using eight Qualisys® OQUS 500 motion analysis cameras at 100 Hz.

Participants walked barefoot for six minutes on a dual-belt instrumented treadmill (R-Mill, MotekForcelink, Netherlands) which was set to the self-selected speed calculated from the GaitRITE™ walkway. Four consecutive strides were recorded at each recording interval, minute one (1 min), three (3 min), five (5 min) and six (6 min).

After completion, a resting muscle activity trial was recorded. To elicit maximal voluntary isometric contractions (MVIC), Humac Norm Isokinetic Dynamometer (Computer Sports Medicine Inc., USA) procedures were used. Knee flexors and extensors were tested at 45 degrees of knee flexion. A standing unilateral plantarflexion exercise was also completed (Rutherford et al., 2011b). Following at least one practice and warm-up contraction, two, three-second maximal isometric contractions were completed. A 40-second rest period separated each contraction, and standardized verbal encouragement was given.

### 2.3. Data processing

Custom programs, written in MatLab™ 2015b (Mathworks Inc., USA) were used to complete data processing. Technical and local anatomical bone embedded pelvis, thigh, shank and foot coordinate systems were derived from physical spheres and virtual points. Marker motion and kinematic data were smoothed using 6 Hz - low pass 4th order Butterworth recursive filter. Ground reaction force data were low pass filtered using a 30 Hz - low pass, 4th order Butterworth recursive filter prior to processing. Knee joint angles were calculated using a 6-degree of freedom model through Cardan/Euler rotations as previous (Rutherford et al., 2015). Net external moments were calculated using an inverse dynamics model (Vaughan et al., 1999). Moments were projected into a non-orthogonal joint coordinate system, amplitude normalized to body mass (Nm/kg) and low pass filtered (10 Hz – 4th order, recursive Butterworth) prior to analysis (Dunphy et al., 2016). All raw EMG signals were bandpass filtered (10-500 Hz - 4th order recursive Butterworth), corrected for resting bias, rectified and filtered using a Butterworth, 6 Hz recursive, 4th order, low-pass filter. Gait waveforms were amplitude normalized to the highest 100 ms window from the MVIC trials (Hubley-Kozey et al., 2006).

Motion and EMG waveforms were time normalized to the gait cycle (beginning and ending at heel strike) whereas moment waveforms were time normalized to the stance phase (beginning at heel strike and