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Effect of gait retraining for reducing ambulatory knee load on trunk biomechanics and trunk muscle activity

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ABSTRACT

The purpose of this study was to test the hypothesis that walking with increased medio-lateral trunk sway is associated with lower external knee adduction moment and lower extremity muscle activation, and higher external ipsilateral trunk moment and trunk muscle activity than walking with normal trunk sway in healthy participants. Fifteen participants performed walking trials with normal and increased medio-lateral trunk sway. Maximum trunk sway, first maximum knee adduction moment, lateral trunk bending moment, and bilateral vastus medialis, vastus lateralis, gluteus medius, rectus abdominis, external oblique and erector spinae muscle activity were computed. Walking with increased trunk sway was associated with lower maximum knee adduction moment (95% confidence interval (CI): 0.50–0.62 Nm/kg vs. 0.62–0.76 Nm/kg; $P < .001$) and ipsilateral gluteus medius (−17%; $P = .014$) and erector spinae muscle activity (−24%; $P = .004$) and greater maximum lateral trunk bending moment (+34%; $P < .001$) and contralateral external oblique muscle activity (+60%; $P = .009$). In all participants, maximum knee adduction moment was negatively correlated and maximum trunk moment was positively correlated with maximum trunk sway. The results of this study suggest that walking with increased trunk sway not only reduces the external knee adduction moment but also alters and possibly increases the load on the trunk. Hence, load-altering biomechanical interventions should always be evaluated not only regarding their effects on the index joint but on other load-bearing joints such as the spine.

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1. Introduction

Abnormal mechanical loading of the knee joint has been associated with an increased risk for the degeneration of articular cartilage [1] and the presence of medial knee joint osteoarthritis [2,3]. The external knee adduction moment measured during walking is often used as a surrogate for the load distribution between the medial and lateral compartment because it correlates with the medial compartment contact force [4]. During the stance phase of walking the ground reaction force vector passes medially to the knee joint center, hence generating an external knee adduction moment. The first maximum knee adduction moment is higher in patients with medial knee osteoarthritis than in healthy participants [5,6] and has been associated with the progression [1,7] and severity [8] of knee osteoarthritis.

The efficacy of different gait interventions for reducing the maximum knee adduction moment has been explored. Successful methods include reducing walking speed [8,9], toe-in gait [10,11], walking with increased mediolateral trunk sway [10,12–14], or a combination of different methods [15,16]. In healthy participants, walking with 10° greater than normal mediolateral trunk sway amplitude resulted in 20% [14] and 65% [12] reductions of the first maximum knee adduction moment and in patients with medial knee osteoarthritis a reduction of 15% was reported [13]. Moreover, the amount of mediolateral trunk sway during walking partly explained differences (13%) in the first maximum knee adduction moment among patients with medial compartment knee osteoarthritis [17].

Ipsilateral and contralateral abdominal and back muscles are major contributors to trunk movements in the frontal plane [18]. During normal walking, the erector spinae muscle is mainly active around contralateral initial contact [19], and the external

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oblique muscle is active at least 75% of the gait cycle (longer with increasing walking speed) with highest activity during contralateral stance phase [19,20]. The gluteus medius muscle plays an important role in the control of the frontal plane trunk movement [18]. Increasing mediolateral trunk sway moves the body's center of mass closer to the hip joint presumably requiring less gluteus medius activity for stabilizing the hip and pelvis during single limb support [21]. However, it presumably entails more complex trunk movement control and hence poses additional demands on the trunk muscles. Moreover, greater trunk sway may increase the load in the lower back. While increasing trunk sway during walking effectively decreases the maximum knee adduction moment, its effects on trunk biomechanics and muscle activation are unknown.

The purpose of this study was to test the hypothesis that walking with increased trunk sway is associated with lower external knee adduction moment and lower extremity muscle activation, and higher external ipsilateral trunk moment and trunk muscle activity than walking with normal trunk sway in healthy participants.

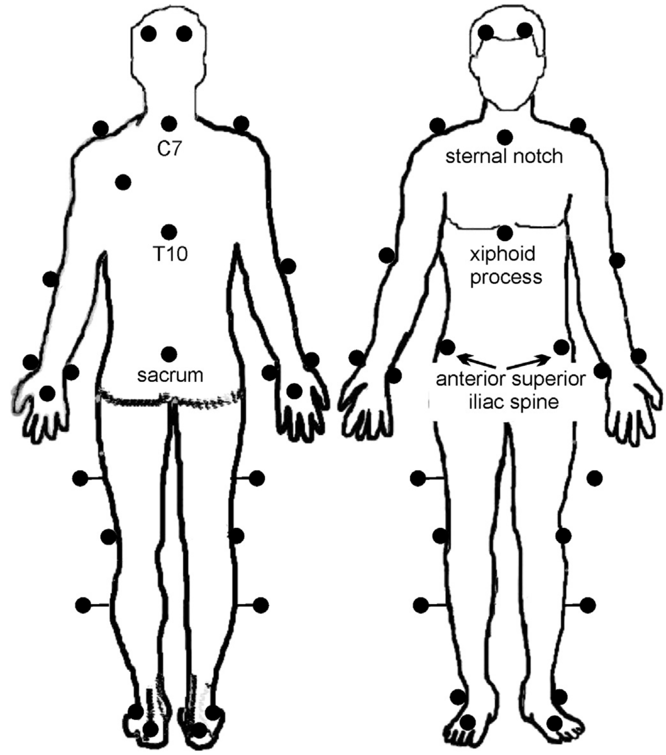

Fig. 1. Marker placement on the lower body and trunk according to the PlugIn–Gait model [22–24]. Markers on sacrum and anterior superior iliac spines defined the pelvis segment and markers on spinous process of C7 and T10, sternal notch, and xiphoid process defined the thorax segment. Please note that the knee alignment device was applied to the knee for the static trials (not shown in this figure).

2. Methods

2.1. Participants and procedures

Fifteen healthy participants (seven males, eight females; age: 30.0 ± 8.7 years; body mass: 70.5 ± 11.7 kg; height: 1.77 ± 0.08 m) participated in this study after providing informed consent. Exclusion criteria were current lower extremity or lower back pain and any neuromuscular disorders affecting gait. The study was approved by the local ethics committee.

Gait analysis was performed using a 12-camera motion analysis system (Vicon, Oxford, UK; sampling rate: 200 Hz), two force plates (Kistler, Winterthur, Switzerland; sampling rate: 2400 Hz) and a 12 channel surface electromyography (EMG) system (Biovision, Wehrheim, Germany, sampling rate 2400 Hz). For each participant, we collected six walking trials with normal and six walking trials with increased mediolateral trunk sway. Participants walked with their personal athletic shoes at their self-selected speed on a 10-m walkway. For walking with increased trunk sway, participants were instructed to increase the side-to-side motion of the upper body [12]. All participants were allowed several practice trials until they felt comfortable. The examiner adjusted the starting point to ensure that participants hit the force plates centrally as they were not informed about the force plates.

2.2. Kinematics and kinetics

Reflective markers were placed on anatomical landmarks according to the full body PlugIn–Gait model [22–24] (Fig. 1) with the knee alignment device for the static standing trial. The Vicon Nexus software was used to calculate 3-dimensional kinematics of the ankle, knee, hip and trunk and resultant external joint moments for the ankle, knee, hip, and trunk. The net external muscle moments at each joint of the lower limbs and at L5 throughout the gait cycle were calculated using an inverse dynamics approach based on body segment parameters and kinematic and force plate data.

All calculated waveforms were time normalized to one stance phase (0–100% from initial contact to toe-off). Maximum trunk sway was defined as the maximum ipsilateral angle of the thorax segment in the frontal plane relative to the global reference system. Maximum trunk moment was defined as the maximum external ipsilateral moment in the trunk–pelvis joint in the frontal plane. Maximum knee adduction moment was defined as the first maximum of the external knee adduction moment. The time of these parameters was recorded for each trial. Between-trial reliability for trunk sway, calculated as the standard error for each participant and condition, was below 0.2° for walking with normal and below 1.2° for increased trunk sway.

2.3. Electromyography

Round bipolar Ag/AgCl electrodes (Noraxon USA Inc., Scottsdale, AZ, USA; diameter: 10 mm; inter-electrode distance: 20 mm) were placed bilaterally on the vastus medialis, vastus lateralis, gluteus medius, rectus abdominis, external oblique and erector spinae (level L5) muscles after shaving and cleaning the skin with alcohol [25]. To reduce movement artifacts, amplifiers and cables were taped to the skin. The ground electrode was placed over the tibial tubercule. Bilateral EMG signals (recording system: Biovision, Wehrheim, Germany. Bandwidth 10–700 Hz, gain range 1000–5000) were recorded simultaneously with kinematic and kinetic data. All EMG signals were full-wave rectified and filtered using a zero-lag moving average filter with a window of 100 sampling points to obtain EMG envelopes. The EMG envelopes for each muscle and participant were normalized to its ensemble mean of normal walking [26]. For each trial, EMG envelopes were time-normalized to stance phase, and the mean relative intensity between initial contact and time of maximum knee adduction moment was calculated for each muscle.

2.4. Statistics

For each participant, data from either only left or right gait cycles were used for further analysis. The side was chosen randomly (seven left, eight right). All statistical analyses were performed in SPSS version 22.0 (IBM Corporation, Armonk, NY).

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