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Full gait cycle analysis of lower limb and trunk kinematics and muscle activations during walking in participants with and without ankle instability

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ABSTRACT

Background: Chronic ankle instability (CAI) has previously been linked to altered lower limb kinematics and muscle activation characteristics during walking, though little research has been performed analysing the full time-series across the stance and swing phases of gait.
Research Question: The aim of this study was to compare trunk and lower limb kinematics and muscle activity between those with chronic ankle instability and healthy controls.
Methods: Kinematics and muscle activity were measured in 18 (14 males, 4 females) healthy controls (age 22.4 ± 3.6 years, height 177.8 ± 7.6 cm, mass 70.4 ± 11.9 kg, UK shoe size 8.4 ± 1.6), and 18 (13 males, 5 females) participants with chronic ankle instability (age 22.0 ± 2.7 years, height 176.8 ± 7.9 cm, mass 74.1 ± 9.6 kg, UK shoe size 8.1 ± 1.9) during barefoot walking trials, using a combined Helen Hayes and Oxford foot model. Surface electromyography (sEMG) was recorded for the tibialis anterior and gluteus medius. Full curve statistical parametric mapping was performed using independent and paired-samples T-tests.
Results: No significant differences were observed in kinematic or sEMG variables between or within groups for the duration of the swing phase of gait. A significantly increased forefoot-tibia inversion was seen in the CAI affected limb when compared to the CAI unaffected limb at 4–16% stance ($p = 0.039$). No other significant differences were observed.
Significance: There appears to be no differences in muscle activation and movement between CAI and healthy control groups. However, participants with CAI exhibited increased inversion patterns during the stance phase of gait in their affected limb compared to their unaffected limb. This may predispose those with CAI to episodes of giving way and further ankle sprains.

1. Introduction

Lateral ankle sprains are one of the most common musculoskeletal injuries in both general and sporting populations [1]. Following an acute ankle sprain, it is suggested that 32–74% of individuals have residual symptoms such as recurrent sprains, episodes of giving way and/or perceived instability [2]. Chronic ankle instability (CAI) is defined as 'a history of recurrent ankle sprains and the sensation of giving way' [3]. Long term, links have been established between the development of osteoarthritis and a history of CAI, suggesting abnormal kinematic movement patterns adopted may increase repetitive cartilage damage to the medial ankle [4]. Greater understanding of the biomechanics associated with CAI may aid the development of preventative measures.

Walking is of high importance in daily life, and is often problematic for people with CAI who complain of giving way sensations on uneven and level surfaces [5]. Research suggests that the position of the affected ankle joint at specific time points during the gait cycle may predispose an ankle to injury [6]. This may be associated with or caused by ankle joint instability. Research analysing frontal plane ankle kinematics during walking observed increased ankle inversion that corresponded to greater ankle inversion during more sport-specific tasks such as jump-landing [7]. Gait analysis is often used in the development of rehabilitation and injury prevention protocols, therefore any changes in full body gait kinematics need to be investigated, and where possible accounted for, as these may impact not only walking but other more dynamic movements.

Previous literature investigating sEMG found hip abductor weakness

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to be associated with acute ankle sprains, though it is unclear whether this is a cause or an effect of the sprain [8]. Koldenhoven et al. [9] reported increased gluteus medius activation in the late stance and early swing phase of walking in CAI participants, suggesting this may be a coping mechanism used to generate a wider base of support, or to increase lower limb stability. Decreased tibialis anterior activation was also observed resulting in increased ankle plantarflexion prior to heel strike. This loose-packed position (ligaments and the joint capsule lax and minimal joint surface contact) has been found to be unstable [10], suggesting an increased risk of ankle sprains.

Previous literature investigating CAI during walking has modelled the foot as one rigid segment [11,12], however the foot is composed of 26 bones and 20 articulated joints with a number of complex interactions [13]. Rigid segment modelling excludes motion between different segments of the foot providing inadequate information on the biomechanics of the foot [11]. De Ridder et al. [14] appears to be the first study to analyse walking using a multi-segmental foot model, comparing the use of the Ghent Foot Model to a rigid foot model in participants with CAI, copers (no symptoms of instability after a recent ankle sprain) and control participants. Results lead the authors to conclude that the multi-segmental foot model provided greater details of the intricacies of the foot, showing differences between segments when comparing groups.

Upper body kinematic analysis should be considered when investigating changes in the lower extremities as there may be a significant relationship with changes observed in proximal segments [15]. The body is a multi-linked system with the rectus femoris, hamstrings and gastrocnemius muscles crossing the hip, knee and ankles. The kinetic chain concept suggests that movement of the trunk during landing (which accounts for 35.5% body mass) will also have an impact on motion of the hip and therefore knee and ankle [16]. To the authors' knowledge, no research has combined trunk kinematics with a full lower limb and multi-segmental foot model to address, in combination, the possible proximal and distal differences between groups.

Prior research reports joint angles and muscle activation characteristics at discrete time points during walking [9,12], rather than whole kinematic time-series curves. Biomechanical data is one dimensional (1D) (time and kinematic or force trajectories) therefore this may result in focus bias or missing potential significance or trends during other phases of the gait cycle [17]. Statistical parametric mapping (SPM) is a concept introduced to biomechanics from brain research [18] which enables curve analysis across the whole movement [17]. Comparison between SPM and time series analysis using confidence intervals concluded SPM to be the most suitable method for analysis of 1D data, due to increased generalisability of probabilistic conclusions (with the use of hypothesis testing techniques) and the ability to present results in a more consistent manner aiding interpretation of findings [19]. De Ridder et al. [14] used SPM to compare foot kinematics between participants with CAI, copers and controls, identifying exact time periods of significantly increased forefoot inversion within the stance phase of walking.

It is suggested that combined analysis of the trunk, hip, knee and multi-segmental foot kinematics and sEMG activation patterns across the stance and swing phases of gait will provide greater insight into possible differences that exist, not just within the foot, but across the full kinetic chain. This may provide greater insight to clinicians rehabilitating those with ankle instability and may highlight areas of importance in the reduction of future ankle sprains. The aim of this study was to compare trunk, hip, knee and multi-segmental foot kinematics and muscle activation during the stance and swing phase of walking between participants with CAI and healthy controls.

Table 1
participant inclusion and exclusion criteria.

Inclusion	Exclusion
- 18–35 years old - Participation in team sport a minimum of twice a week	Declaration of the following during health screen: - acute lower limb injury in the past 3 months - use of prescribed or shop bought orthotics - history of neurological disease - lower extremity pathological abnormality that would impair or alter motor performance - balance or motion disorders - history of fracture requiring realignment - history of lower extremity surgery

2. Methods

2.1. Participants

Eighteen (14 males, 4 females) healthy controls (age 22.4 ± 3.6 years; height 177.8 ± 7.6 cm; mass 70.4 ± 11.9 kg; UK shoe size 8.4 ± 1.6), and 18 (13 males, 5 females) participants with CAI (age 22.0 ± 2.7 years; height 176.8 ± 7.9 cm; mass 74.1 ± 9.6 kg; UK shoe size 8.1 ± 1.9) participated in this study. Ethical approval was granted by the institutional ethics committee prior to testing. Written informed consent was obtained from participants and a health screen questionnaire completed prior to participation. Inclusion and exclusion criteria for participation detailed in Table 1, in accordance with selection criteria outlined by the International Ankle Consortium (IAC) [2].

Participants were allocated into the control group or the CAI group based on results of the Identification of Functional Ankle Instability (IdFAI) questionnaire, where a score of ≥11 indicated ankle instability in accordance with IAC guidelines [2]. In the instance of bilateral ankle sprains, the involved limb was selected based on the participant's perception of greater instability. As the researcher was blinded to the questionnaire outcome, the affected limb could not be identified exclusively as either the dominant or non-dominant limb. Therefore, the affected limb was randomly matched to a control limb to adjust for the dominance effect. Limb dominance was determined by asking which leg they would use to kick a ball [10]. Mean IdFAI score for the control group was 3.71 ± 3.13 and 19.1 ± 6.25 in the CAI group's affected limb.

2.2. Protocol

Participants completed a 5-min warm up on a cycle ergometer (Monark Ergomedic 874E, Sweden) at 60 W. Electromyographic data were recorded bilaterally for the gluteus medius and tibialis anterior using a DataLINK data acquisition system (Biometrics Bluetooth unit W4X8, Biometrics Ltd, Gwent, UK) sampling at 1000 Hz with pre-amplified SX230-1000 electrodes. Participants' skin was prepared for electrode placement and electrodes placed in accordance with SENIAM guidelines [20]. Tibialis anterior electrodes were placed at a third of the line between the tip of fibula and the tip of medial malleolus. Gluteus medius electrodes were placed half way between the crista iliaca and the trochanter. For each muscle, three maximal contractions were performed for a 5 s duration, 1-min rest between trials. Peak activation of the three trials was identified as the maximum voluntary isometric contraction (MVIC) which was used to allow comparison between participants' sEMG data and to voluntary contractions to inspect for crosstalk. Gluteus medius MVIC was performed in side lying with the participant maximally abducting their hip (positioned mid-range) into a rigid strap positioned just above the knee [21]. Tibialis anterior MVIC