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Multi-segment foot landing kinematics in subjects with chronic ankle instability

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ABSTRACT

Background: Chronic ankle instability has been associated with altered joint kinematics at the ankle, knee and hip. However, no studies have investigated possible kinematic deviations at more distal segments of the foot. The purpose of this study was to evaluate if subjects with ankle instability and copers show altered foot and ankle kinematics and altered kinetics during a landing task when compared to controls.
Methods: Ninety-six subjects (38 subjects with chronic ankle instability, 28 copers and 30 controls) performed a vertical drop and side jump task. Foot kinematics were obtained using the Ghent Foot Model and a single-segment foot model. Group differences were evaluated using statistical parametric mapping and analysis of variance.
Results: Subjects with ankle instability had a more inverted midfoot position in relation to the rearfoot when compared to controls during the side jump. They also had a greater midfoot inversion/eversion range of motion than copers during the vertical drop. Copers exhibited less plantar flexion/dorsiflexion range of motion in the lateral and medial forefoot. Furthermore, the ankle instability and coper group exhibited less ankle plantar flexion at touchdown. Additionally, the ankle instability group demonstrated a decreased plantar flexion/dorsiflexion range of motion at the ankle compared to the control group. Analysis of ground reaction forces showed a higher vertical peak and loading rate during the vertical drop in subjects with ankle instability.
Interpretation: Subjects with chronic ankle instability displayed an altered, stiffer kinematic landing strategy and related alterations in landing kinetics, which might predispose them for episodes of giving way and actual ankle sprains.

1. Introduction

Ankle sprains are one of the most frequently observed sport injuries, representing between 10% and 30% of all registered musculoskeletal injuries (Fong et al., 2007). In 80% of the cases, the sprain involves an inversion trauma with damage to the lateral ligaments (Fong et al., 2007). In the United States, up to 27,000 ankle sprains occur daily (Renstrom and Konradsen, 1997). As a consequence of sustaining an initial ankle sprain, many patients experience residual symptoms such as pain, swelling and even re-sprains. Moreover, up to 53% of all patients report a residual condition described as chronic ankle instability (CAI) (van Rijn et al., 2008). CAI has been defined as the repetitive occurrence of instability, resulting in numerous ankle sprains (Hertel, 2002). In view of the high incidence, the impact on sports participation (Anandacoomarasamy and Barnsley, 2005; Konradsen et al., 2002) and the long-term degenerative consequences (Valderrabano et al., 2006), it is necessary for clinicians to gain a better understanding of the underlying mechanisms.

Ankle sprains often occur during activities, which involve jumping, landing and turning, e.g., during sports such as basketball, volleyball and soccer (Yeung et al., 1994). Inadequate joint control during landing in particular might be a key factor as biomechanical research indicates that ankle joint kinematics can reveal detriments in the capacity to modify and control the high loading associated with landing (Zhang et al., 2000). Differences in the timing and magnitude of ground reaction forces (GRF) between subjects with CAI and controls have also been reported (Caulfield and Garrett, 2004; Delahunt et al., 2006a). In addition, research on landing kinematics in subjects with CAI revealed several kinematic differences not only at the level of the ankle but also at more proximal joints, i.e., the knee and the hip (Caulfield and Garrett, 2002; Delahunt et al., 2006a; Gribble and Robinson, 2010). For the ankle joint, a more inverted position of the ankle has been shown during the postlanding phase of a stop-jump landing task (Lin et al., 2011) and during the pre- and postlanding phase of lateral hop (Delahunt et al., 2007), as well as a greater ankle dorsiflexion prior to and post landing in a

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single leg jump (Caulfield and Garrett, 2002). Notwithstanding some conflicting results, possibly caused by the different tasks observed, the observation of lower limb joint kinematics may well offer a window into the underlying mechanisms of CAI.

Although current research has focused on kinematics at the ankle and more proximal joints in subjects with CAI, to the author's knowledge, no studies have investigated the kinematic adaptations during landing distal to the ankle, i.e., at the foot. Previous research during landing has modeled the foot as one rigid segment. This assumption ignores the functional anatomy of the ankle–foot complex, yet mid- and forefoot characteristics have been acknowledged to potentially play a role in the mechanism of an ankle sprain (Morrison and Kaminski, 2007). In addition, rearfoot and medial forefoot kinematics have been shown to differ between subjects with CAI and healthy controls during gait (De Ridder et al., 2013). Insight in foot function during landing tasks could therefore be enhanced by the use of multi-segment foot models (Rankine et al., 2008). Moreover, with the forefoot being first in contact with ground during landing, differences in foot segment kinematics may also influence the ankle and more proximal joints in the kinetic chain. Multi-segment foot kinematics might also reveal impaired force dissipation strategies at touchdown, which could put a subject with CAI at increased risk for re-spraining their ankle.

The goal of this study was to identify differences in ankle and multi-segment foot kinematics during the impact phase of a landing task in subjects with CAI compared to a control group. In addition, single-segment foot kinematics were also calculated to allow comparison of results with existing literature. To further understand the CAI mechanism, we also included a coper group who had previously sustained an ankle sprain but had not experienced any negative effects following their rehabilitation and had since returned to their pre-injury sporting level. For this coper group, subjects with a recent ankle sprain were chosen with the aim of identifying active coping strategies in the period during which an individual is most susceptible to sustain a re-sprain. For some reason, these subjects had not developed a chronic condition as of yet and therefore were interesting to consider as a separate group. Based on the ankle sprain mechanism, a more inverted ankle joint position was hypothesized in subjects with CAI. Furthermore, based on previous multi-segment foot research (De Ridder et al., 2013), a more inverted medial forefoot was expected in subjects with CAI. Vertical ground reaction force (GRF) patterns were also evaluated to reveal whether peak force and loading rate were altered.

2. Methods

2.1. Subjects

A total of 96 participants took part in this study (Table 1). Thirty-eight subjects with CAI (19 males and 19 females, 5 (SD 3) months to last sprain, 10 (SD 13) sprains annually), 28 copers (14 males and 14 females, 11 (SD 5) months to last sprain) and 30 controls (12 males and 18 females) were recruited. All subjects in the CAI group met the following inclusion criteria: (1) a history of at least one ankle sprain which resulted in pain, swelling and stiffness prohibiting participation in sport, recreational or other activities for at least 3 weeks; (2) repeated ankle sprains; (3) presence of giving way; (4) a feeling of weakness around the ankle, and (5) a decreased functional participation (recreational, competitive or professionally) as a result of the ankle sprains. The copers were defined as subjects with a history of an ankle sprain in the last two years, but who had no characteristics of CAI. Subjects in the control group had no lower leg injuries in the past 2 years. All subjects had to perform at least 1.5 hours of cardiovascular activity per week. Exclusion criteria were a history of ankle fracture or surgery, lower limb pain at the time of testing, ankle sprain in the last 3 months, and equilibrium deficits. This study was approved by the local ethics committee and all subjects signed the informed consent.

Table 1
Group mean (SD) for demographic variables.

	CON ($n = 30$)	COP ($n = 28$)	CAI ($n = 38$)
Age (years)	25.7 (1.8)*	20.3 (1.9)*	22.1 (3.4)*
Height (cm)	173.6 (9.4)	177.6 (10.2)	175.4 (8.3)
BMI	21.8 (1.8)	22.1 (1.7)	23.1 (3.4)
FADI	100 (0.0)[a]	99.0 (2.4)[a]	89.2 (7.2)[a]
FADI-S	100 (0.0)[b]	96.2 (4.8)[b]	72.7 (10.2)[b]

* Differences between groups are non-significant ($p > 0.05$) except for age for control (CON) in comparison with CAI and coper (COP) ($p < 0.001$), and between CAI and COP ($p = 0.018$).

[a] FADI, Functional Ankle Disability Index, was significantly lower in the CAI group compared to both the control group and the coper group ($p < 0.001$).

[b] FADI-S, Functional Ankle Disability Index–sport subscale score, was significantly lower in the CAI group compared to both the control group and the coper group ($p < 0.001$).

2.2. Experimental procedure

Baseline characteristics were registered for all subjects. The Foot and Ankle Disability Index (FADI) and its sport subscale (FADI-S) were completed by all participants to assess the disability of the ankle during daily living (Hale and Hertel, 2005). Group characteristics are summarized in Table 1.

All subjects performed two landing tasks. First, subjects carried out a single leg vertical drop from a 40 cm high box. They were instructed not to jump but rather to step down and to maintain balance for three seconds, starting out on the opposite leg to control drop height and land onto the force plate. Hands had to be kept on the hips throughout the whole trial and subjects were asked to look straight forward. Trials were discarded if the subject jumped from the box, if the foot shifted after landing, if hands were used to restore balance, if there was contact between both legs in an attempt to keep balance or if the contralateral foot touched the ground. Each subject performed 3 vertical drops. Second, after a 5-min rest, subjects performed a maximal side jump. They started in a single leg stance on their contralateral foot, were asked to push off and jump maximally sideways and land with their tested leg on the force plate. The foot position upon landing had to be perpendicular to the line of movement to eliminate compensation by external rotation of the foot. A jump was discarded if the subject required any corrections following landing as described above. Each subject performed 3 side jumps. Subjects were permitted a period of practice prior to testing.

All subjects were barefooted during testing, and none complained of any discomfort during the functional tasks. In the CAI group, the most unstable ankle based on the subject's medical history was investigated. For the copers, the ankle sprained most recently was selected. In the control group, the tested ankle was chosen randomly.

Spherical reflective surface markers (7 mm) were placed on anatomical landmarks according to the Ghent Foot Model. This six-segment model tracked the shank, rear foot, midfoot, medial and lateral forefoot and the hallux as individual functional segments. The single-segment foot was defined by markers on the calcaneus, the lateral malleolus and the head of the first and fifth metatarsal head. A 6 camera opto-electronic system (500Hz, OQUS 3, Qualysis, Gothenburg, Sweden) was synchronized with a force plate (500 Hz, AMTI, Watertown, Massachusetts) embedded underneath the landing zone. A visual record was captured by means of a normal video camera (Sony, 25 Hz).

2.3. Data analysis

Visual 3D (C-motion, Germantown, MD) was used to process the kinematic and kinetic data (QTM, Qualisys). Marker data were filtered using a fourth order Butterworth low-pass filter at 15Hz, with 50 points reflected. Euler rotations (X-Y-Z, representing respectively dorsi-/plantar flexion, eversion/inversion, ab-/adduction) were used to calculate motion between the defined segments in the different planes