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Short communication

A laboratory captured 'giving way' episode during a single-leg landing task in an individual with unilateral chronic ankle instability

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ABSTRACT

An episode of 'giving way' at the ankle is described as excessive inversion of the rearfoot that does not result in an acute ankle sprain and is a unique feature associated with chronic ankle instability (CAI). Limited data currently exists describing the preparatory movement patterns and those that occur during an episode of 'giving way. Therefore, this case report describes the movement patterns and the forces generated during an unintentional 'giving way' captured while an individual with unilateral CAI was performing a single-leg landing task in a research laboratory. The participant completed five single-leg landing trials for both limbs. 3D lower extremity kinematics and kinetics for the sagittal and frontal plane were extracted from 200 ms before and after initial contact (IC). Relative to the affected and un-affected single-leg landing trials, the 'giving way' episode was characterized by an increase in plantarflexion and hip extension moments before and after IC. The plantarflexion deviation dissipated (50 ms post-IC) and was followed by excessive ankle inversion. The ankle began to plantarflex again (150 ms post-IC) and the knee extended (50 ms post-IC) and adducted (100 ms post-IC). As a result, the ankle inversion angle plateaued at 150 ms post-IC. Furthermore, large sagittal plane internal joint moments were observed. In the frontal plane, the 'giving way' trial generated a large inversion joint moment which was counteracted by a large internal eversion joint moment. The observed plantarflexion and knee extension and adduction after initial contact likely contributed to preventing the ankle from continuing to invert and avoid an ankle sprain.

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1. Introduction

A lateral ankle sprain is a common injury that typically occurs during a sport or recreational activity (Doherty et al., 2014; Hootman et al., 2007). Previous researchers have reported on the movement profiles of accidental ankle sprain captured during laboratory studies (Gehring et al., 2013; Kristianslund et al., 2011; Terada and Gribble, 2015) or through video analysis of injuries during competition to better understand the mechanics behind an ankle sprain (Fong et al., 2012; Mok et al., 2011; Panagiotakis et al., 2017). These reports suggest that an ankle sprain is accompanied by excessive ankle inversion and internal rotation and may occur in the absence of plantarflexion.

After an ankle sprain, some patients never fully recover and develop what is commonly referred to as chronic ankle instability (CAI) (Anandacoomarasamy and Barnsley, 2005; Verhagen et al., 1995). A unique feature associated with this clinical pathology is experiencing repetitive episodes of 'giving way' at the ankle (Gribble et al., 2014). This is best described as an inversion of the rearfoot during or after initial contact that does not result in a new acute lateral ankle sprain (Gribble et al., 2014). Remus et al. (2018) reported on a laboratory captured 'giving way' episode in an individual with CAI and recorded high rotational velocities around the ankle complex using inertial measurement units (IMUs). While this was the first published case report, similar analyses surrounding this unique feature are needed to continue to improve rehabilitation and injury prevention methods by understanding the mechanics of actual 'giving way' episodes. Therefore, this case report describes the lower extremity kinematics of an unintentional 'giving way' episode captured during a single-leg jump landing task in a research laboratory.

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2. Methods

2.1. Participant

A college-aged male (age = 23, height = 187.96 cm, mass = 97.7 kg) agreed to participate in a case-control study aimed at comparing bilateral lower extremity movement patterns during a single-leg landing task. The inclusion criteria for the case-control study was based on the recommendations set by the International Ankle Consortium (Gribble et al., 2014). Using these recommendations, the participant was classified as having unilateral CAI (Table 1). The participant read and signed an informed consent approved by the university institutional review board.

2.2. Instrumentation

A Vertec vertical jump tester (Sports Imports, Columbus, OH, USA) was used to measure the maximum vertical jump height and to serve as a target during each single-leg landing trial. Reflective markers were placed at selected anatomic landmarks of the pelvis and throughout each leg/foot (McCann et al., 2017). Kinematic data were captured at 200 Hz using four Raptor-E cameras, six Raptor-4S cameras (Motion Analysis Corporation, Santa Rosa, CA) and Cortex 6.2 motion capture software (Motion Analysis Corporation, Santa Rosa, CA) (McCann et al., 2017). Force data were collected at 1000 Hz using an embedded Bertec Force Plate (Bertec FP6090-15-2000; Bertec Inc., Columbus, OH) (McCann et al., 2017). Raw motion capture data for each single-leg landing trial was imported and processed in Visual 3D (version 5, C-Motion, MD). Kinematic and ground reaction force data were filtered at 6 and 12 Hz, respectively, with a fourth-order low-pass Butterworth filter.

2.3. Experimental procedures

Testing the affected limb first, the task required the participant to stand 70 cm from the center of the force plate, jump from two feet in a forward direction, touch a Vertec vane (set to 50% of maximum vertical jump height) and land on the designated limb (Gribble and Robinson, 2009; McCann et al., 2017). After landing the participant was asked to fold his arms across his chest as quickly as possible and balance for five seconds (Gribble and Robinson, 2009; McCann et al., 2017). The participant was given four practices trials before performing five test trials on each leg. Failed trials were identified if the participant missed the Vertec vane, missed the force plate upon landing or was unable to balance for five seconds after landing.

Table 1
Participant characteristics.

	Injured side	Un-injured side
IdFAI	11	0
CAIT	21	30
FADI-ADL (%)	94.23	96.87
FADI-Sport (%)	100	100
# of LAS	3	0
Most recent LAS (months)	60	0
# of 'giving way' in past 6 months	6	0
Received rehabilitation after LAS	No	No
Use of ankle brace/tape	No	No

IdFAI: Identification of Functional Ankle Instability; **CAIT:** Cumberland Ankle Instability Instrument; **FADI-ADL:** Foot and Ankle Disability Index Activities of Daily Living; **FADI-Sport:** Foot and Ankle Disability Index Sport; **LAS:** Lateral Ankle Sprain.

2.4. Data processing

Using Visual 3D processing software, a static standing trial of the participant was first created and aligned with the laboratory coordinate system. From this, a kinematic model consisting of a pelvis and bilateral thigh, shank and foot segments with 36 degrees of freedom was created. The hip joint center was defined using previously described methods (Bell et al., 1990). The knee joint center was defined as the linear distance between the medial and lateral femoral epicondyle markers (Sinclair et al., 2015; Thewlis et al., 2008). The ankle joint center was defined as the linear distance between the markers placed on medial and lateral malleoli (Ounpuu et al., 1991).

Joint rotations were determined based on the initial static trial and were calculated using an x-y-z Cardan angle sequence. Net internal joint moments were calculated using an inverse dynamic procedure and normalized to body weight(kg). Additionally, vertical, anterior-posterior and medial-lateral ground reaction force data was normalized to body weight(kg).

Using previously defined periods examining lower extremity joint kinematics and kinetics during single-leg landing tasks, (Delahunt et al., 2006; Doherty et al., 2015a–c) we extracted time-averaged data from 200 ms(ms) prior to initial contact(IC) to 200 ms post-IC. Initial contact was defined as the instance in which the force plate exceeded 10 N of force (McCann et al., 2017).

2.5. Statistical Analysis

Sagittal and frontal plane joint rotations, internal moments and ground reaction force data for each single-leg landing trial were extracted. Data for the five successful single-leg landing trials for the affected and un-affected sides were averaged and the 95% confidence intervals (CI) were calculated. Areas of nonoverlap between the "giving way" trial and the mean ensemble curves for the affected or unaffected limb were examined across all phases of the landing task. Because of the comparison to a single 'giving way' trial limiting statistical analyses, results will be presented descriptively.

3. Results

While completing the 4th single-leg landing trial for the affected limb, a noticeable abnormal movement pattern occurred at the ankle. This prevented the participant from successfully completing the five second balance after landing because the uninvolved limb touched down shortly post-IC (~300 ms). In agreement with the participants' previous experiences, the research team determined to classify the event as a 'giving way' and not an injury because the participant did not report having elevated levels of acute pain, swelling or a loss of function. After a sufficient amount of time (7–10 min), the participant self-selected to continue and was able to complete the remaining test session without any complaints.

The average (95% CI) for the sagittal and frontal plane kinematics, kinetics, and ground reaction forces for both limbs, as well as the data from the single 'giving way' trial can be found in Figs. 1–3.

3.1. Kinematics

During the 'giving way' trial, the ankle was more plantarflexed and the hip was more extended moments before and after initial contact compared to the average landing pattern for the affected and un-affected limb. Within 50 ms post-IC, the deviation in sagittal plane ankle rotation dissipated compared to the affected limb.

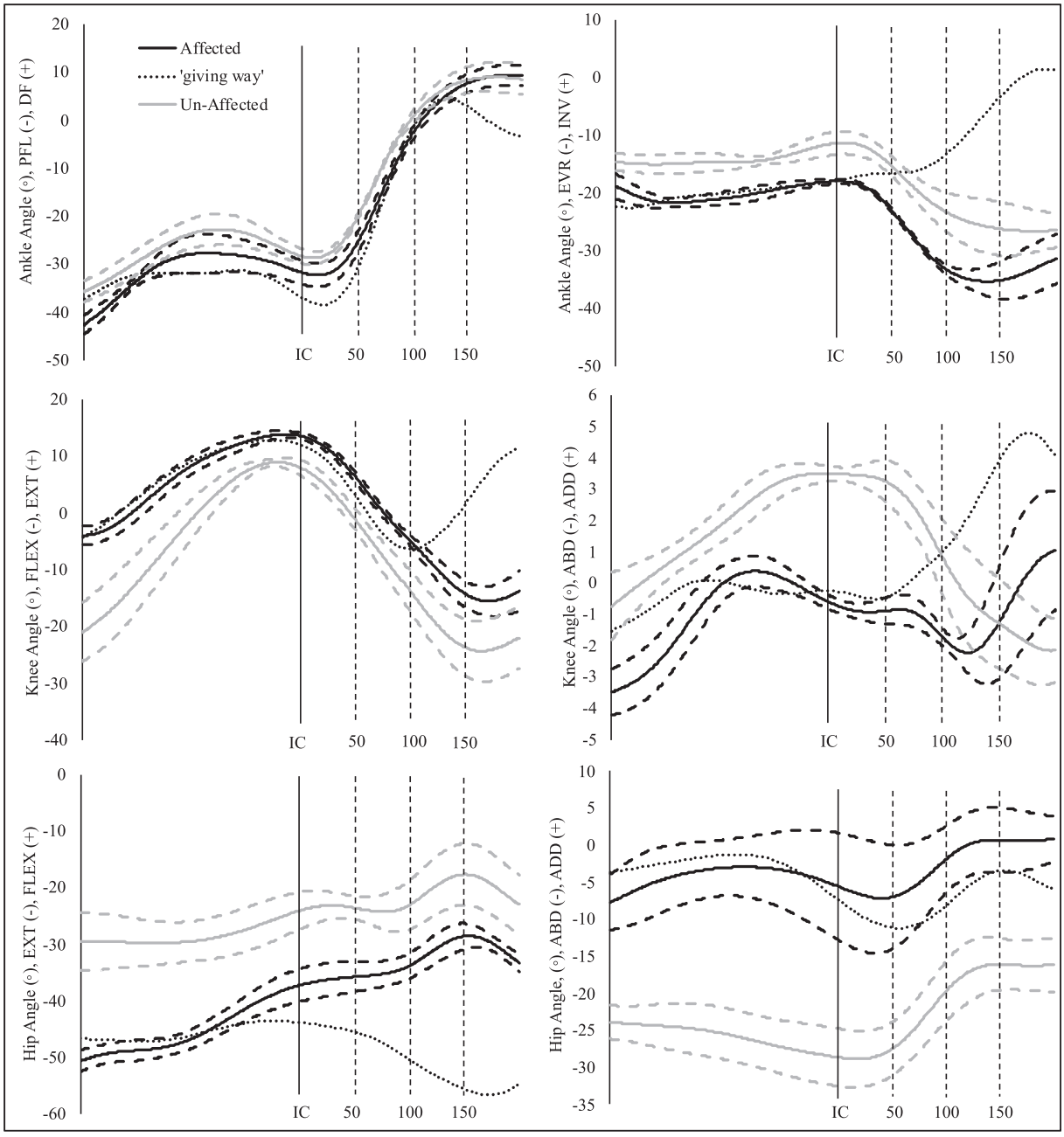

Fig. 1. Average (95% CI) sagittal and frontal plane kinematics at the ankle, knee and hip for the affected, un-affected and 'giving way' trial (200 before and after initial contact).

Between 100 and 150 ms post-IC, there was a sharp decrease in ankle eversion during the 'giving way' trial compared to both limbs. At 150 ms post-IC, the ankle plantarflexed and the frontal angle plateaued. As the ankle started to move towards inversion, the knee adducted and extended at 50 ms and 100 ms post-IC, respectively.

3.2. Joint moments

The 'giving way' trial generated large plantarflexion, knee extension and hip flexion internal joint moments compared to that of the affected and un-affected limbs. Whereas in the frontal plane, the 'giving way' trial produced a large inversion joint moment at the ankle between 50 and 100 ms post-IC. This was quickly followed by an eversion joint moment that peaked after 150 ms post-IC. A similar pattern in joint moments was observed at the knee, whereby an early adduction joint moment was followed by a large abduction moment peaking after 150 ms post-IC.

3.3. Ground reaction force

The 'giving way' trial produced a vertical ground reaction force that was 2x larger than that produced during all other landing trials. Additionally, there was a large laterally directed ground reaction force that peaked shortly after 50 ms post-IC. This was followed by a more medially directed ground reaction force throughout the remaining trial. Finally, the 'giving way' trial first

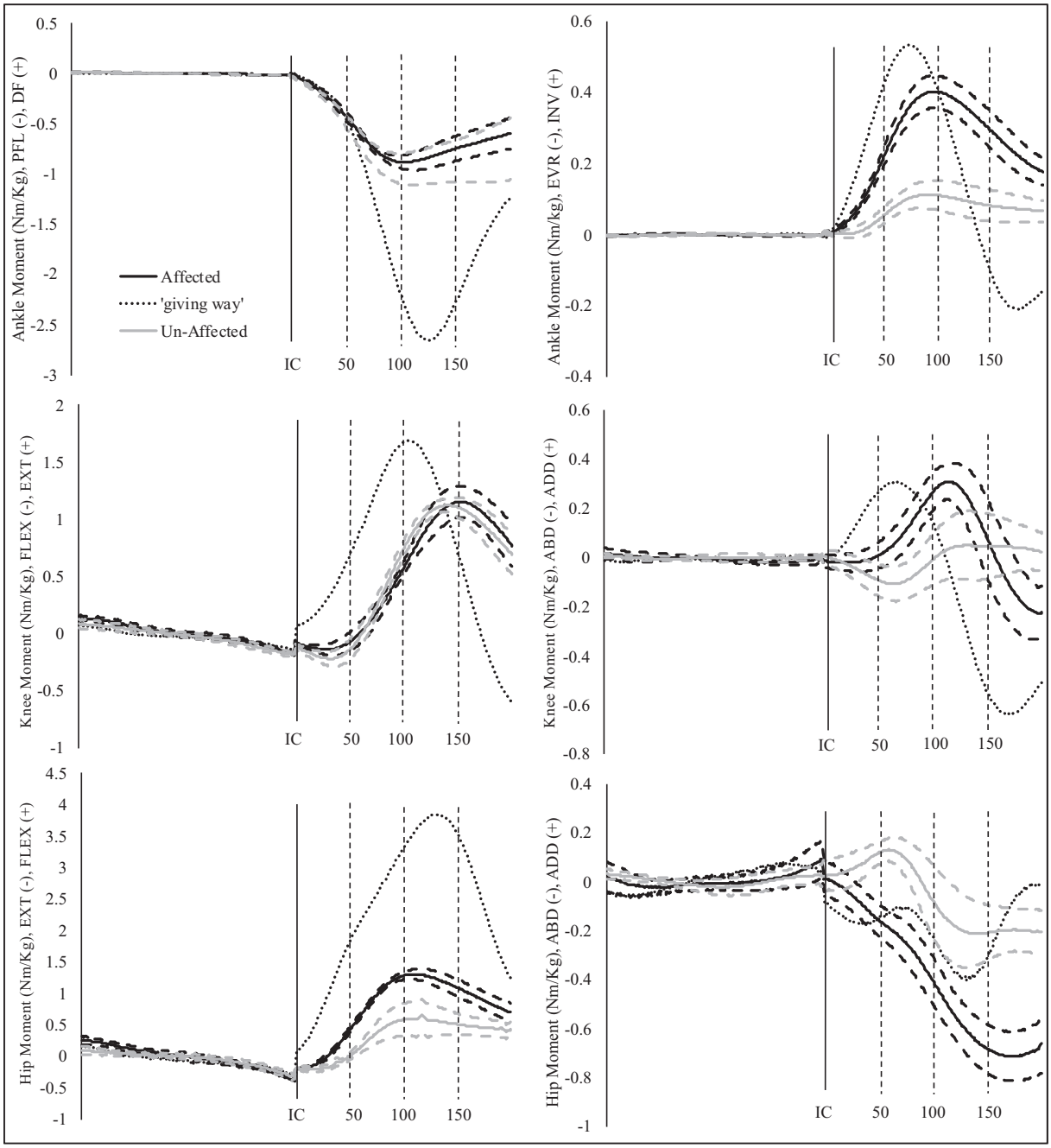

Fig. 2. Average (95% CI) sagittal and frontal plane joint moments at the ankle, knee and hip for the affected, un-affected and 'giving way' trial (200 before and after initial contact).

produced a posterior ground reaction force that quickly transitioned anteriorly.

4. Discussion

We described the lower extremity kinematic and kinetic patterns of a laboratory captured ankle 'giving way' episode that occurred during a single-leg jump landing trial by an individual identified as having unilateral CAI. There has only been one previous research report detailing the movement patterns of a 'giving way' trial in a person with CAI. While performing an Agility T-Test protocol, Remus et al. (2018) recorded large peak plantarflexion (797°/s), internal rotation (1088°/s) and foot adduction (1734°/s) rotational velocities during the early phases of the 'giving way' trial. These high rotational velocities were immediately followed by fast external rotation, abduction and dorsiflexion rotational velocities. The authors speculated that by moving the ankle into a more closed-packed position, the participant was able to prevent an acute injury from occurring (Remus et al., 2018).

To further understand the movement patterns behind an episode of 'giving way', we examined the kinematic and kinetic data before and after ground contact for both the affected and un-affected limbs. First, there were distinct differences throughout the lower extremity before initial contact between limbs for the successful trials. For example, the knee of the affected limb was more extended and abducted compared to the un-affected (Fig. 1). Moreover, the hip of the affected limb was also more extended and adducted. These abnormal movement patterns

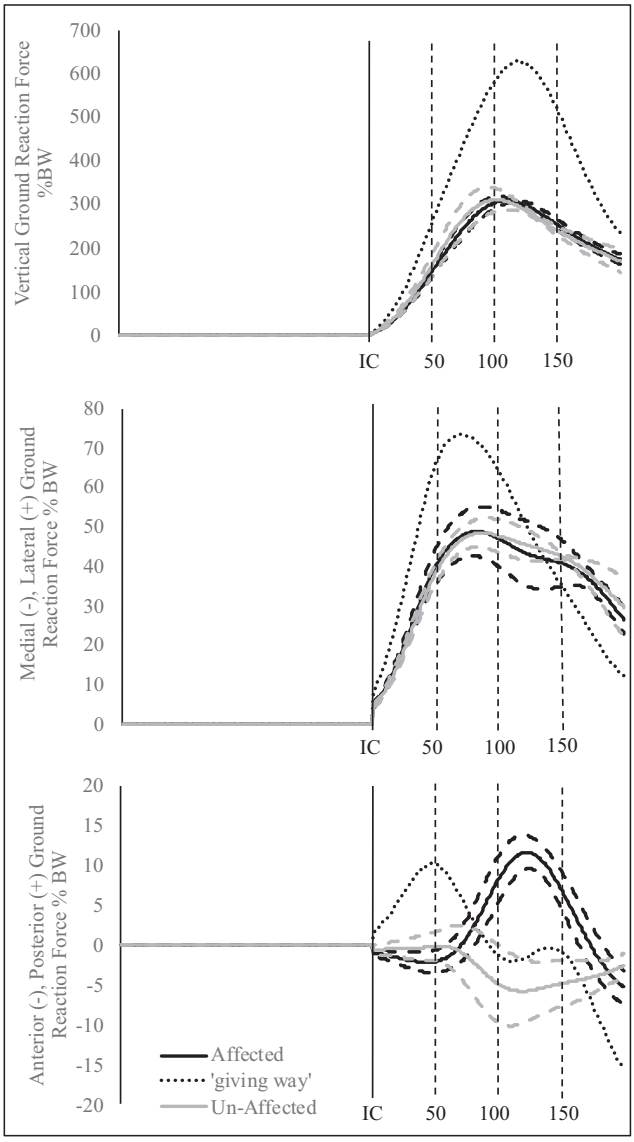

Fig. 3. Average (95% CI) vertical, anterior-posterior and medial-lateral ground reaction force for the affected, un-affected and 'giving way' trial (200 before and after initial contact).

observed before landing continued to persist throughout the 200 ms after ground contact. Taken together, this would suggest that the participant landed with a more erect posture and exhibited a more dynamic knee valgus movement pattern compared to when landing on the un-affected limb. It has been suggested that a more erect landing posture limits the capability of the extensor muscles from being able to absorb the forces that are transmitted throughout the lower extremity after ground contact which may increase the risk of another ankle injury (Blackburn and Padua, 2009; Devita and Skelly, 1992). In fact, previous researchers have postulated that similar abnormal movement patterns at the knee and hip contributed to the injury mechanism of an accidental ankle sprain captured during a cutting task and while performing a jump landing (Gehring et al., 2013; Terada and Gribble, 2015). This landing strategy might also increase the risk of sustaining other injuries at the knee (Kramer et al., 2007). Therefore, it is essential to address the neuromuscular impairments previously demonstrated throughout the entire lower extremity rehabilitation for individuals with CAI. However, the sagittal plane joint angles at the knee and hip seem to be slightly larger than previously published data among individuals with CAI (Doherty et al., 2015c) and in case reports of accidental ankle sprains (Gehring et al., 2013; Terada and Gribble, 2015). The discrepancy between those values presented in the current study and those previously published might be related to the differences in methodology, task and sample size.

Moments before and after initial contact, the 'giving way' trial was characterized by an increase in plantarflexion and hip extension compared to the successful single-leg landing trials for affected and un-affected limbs (Fig. 1). The deviation in sagittal plane ankle orientation dissipated within 50 ms after initial contact. This reduction in plantarflexion joint angle shortly after initial contact is similar to that previously reported and might contribute to the reason for how our participant was able to avoid an ankle sprain (Remus et al., 2018). However, the reduction in plantarflexion joint angle was immediately followed by a decrease in ankle eversion which supports the idea that a 'giving way' results in the ankle moving towards inversion (Gribble et al., 2014). As this was occurring, the participant started to pivot onto his forefoot and adduct and extend his knee. It appears that this movement strategy reflects the participants attempt at preventing the ankle from continuing to invert and reduce the large ground reaction forces generated during the 'giving way' trial (Fig. 3). These large ground reaction forces generated help explain for the large net internal joint moments observed in the sagittal and frontal plane at all three joints (Fig. 2). Previous researchers reporting on an accidental acute ankle sprain suggest that an increased internal inversion joint moment between 100 and 160 ms post-IC likely contributed to the injury mechanism (Gehring et al., 2013; Terada and Gribble, 2015). In comparison, we observed a peak inversion joint moment shortly after IC immediately followed by a large eversion joint moment (Fig. 2). We suspect that this pattern in frontal plane joint moments combined with the observed movement patterns allowed the participant to minimize the strain placed on the lateral ligament complex and experience an episode of 'giving way' rather than an ankle injury.

4.1. Limitations

As with any case report, it is unknown if other individuals with CAI exhibit similar kinematic and kinetic profiles during an episode of 'giving way'. It is possible that other individuals may adopt a different movement strategy during an episode of 'giving way' to avoid an ankle injury. Additionally, we captured this 'giving way' episode in a controlled laboratory environment in which the ground surface was stable, and no other environmental distractions were present. It is possible that additional movement strategies and patterns are observed in a less controlled environment during a 'giving way' episode.

4.2. Conclusion

The episode of 'giving way' described in the current case report was characterized by decreased ankle eversion angle of the ankle. In response to this, there was an increase in ankle plantarflexion and knee extension and adduction. Combined with the observed movement patterns, an increase in ankle eversion moment and reduction in peak ground reaction force likely minimized the strained placed on the static stabilizers to help avoid an ankle injury.

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Declaration of Competing Interest

I affirm that the authors have no financial affiliations (including research funding's) or investment with any commercial organization that has a direct financial interest in any matter included in this manuscript. Additionally, I affirm that the authors have no conflict of interest (i.e. personal associations or involvements as a director, officer, or expert witness).

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