A laboratory captured "giving way" episode in an individual with chronic ankle instability: a short communication

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Abstract

This brief report details the first ever instrument-based motion description of an accidental "giving way" episode of the ankle joint incurred by a recreational male athlete (age = 22 years; height = 1.78 m; body mass = 97 kg) with chronic ankle instability whilst he was performing a change of direction task. Five inertial measurement units, as well as a high-speed video camera captured his lower limb kinematics during the performance of a maximum effort Agility T-Test, including his accidental "giving way" episode. This episode was analysed and compared to a previous trial during which no incident occurred. Analysis of the inertial measurement unit data revealed that the "giving way" episode was characterised by plantar flexion of the ankle joint, as well as internal rotation and adduction of the ankle-foot complex, with peak rotational velocities reaching 797°/s, 1088°/s and 1734°/s, respectively. This instrument-based motion description provides a unique insight into the characteristic features of a "giving way" episode experienced by a recreational athlete with chronic ankle instability. These findings could inform the development of rehabilitation programmes and the design of protective equipment for individuals with chronic ankle instability.

Introduction

Lateral ankle sprain is the most frequent musculoskeletal injury incurred by individuals who participate in sports and recreational physical activities (Doherty et al., 2014b; Fong et al., 2007; Hootman et al., 2007). The recurrence rate of lateral ankle sprain injury is very high (Verhagen et al., 2005) and coincides with the progression of a number of long-term sequalae including pain, persistent swelling, episodes of ankle joint "giving-way", a subjective feeling of ankle joint instability, recurrent sprain and reduced functional capacity (Gribble et al., 2016, 2014a, 2014b, 2013). These long-term sequalae are the characteristic features of chronic ankle instability (CAI) (Delahunt et al., 2010).

Understanding the mechanisms of lateral ankle sprain injury, ideally with biomechanical measures, is a central component required for the development of injury prevention protocols and the design of protective equipment (Bahr, 2005). Numerous reports exist in the published scientific literature, which detail the mechanisms of lateral ankle sprain injury(Andersen et al., 2004; Fong et al., 2012, 2009a, 2009b; Gehring et al., 2013; Kristianslund et al., 2011; Mok et al., 2011; Terada and Gribble, 2015). Whilst the mechanisms of contact and non-contact lateral ankle sprain injury are well documented, little is known about the biomechanical quantities of "giving-way" episodes of the ankle joint. "Giving-way" of the ankle joint has been defined as *"the regular occurrence of uncontrolled and unpredictable episodes of excessive inversion of the rear foot (usually experienced during initial contact during walking or running), which do not result in an acute lateral ankle sprain"* and is a characteristic feature of CAI (Delahunt et al., 2010). Understanding the mechanisms of "giving-way" episodes of the ankle joint in individuals with CAI is required to develop improved rehabilitation and injury prevention programmes. This brief report provides an instrument-based motion description of an episode of "giving-way" of the ankle joint incurred by a male recreational athlete with CAI, whilst he was performing a maximum effort Agility T-Test in a university sports hall.

Injury Case

A recreational male athlete (age = 22 years; height = 1.78 m; body mass = 97 kg) with a history of bilateral CAI volunteered to participate in a case-control study with the aim of investigating the influence of CAI on lower limb movement profiles during the performance of sports-related performance tests. The participant belonged to the study group of CAI participants; as per the criteria endorsed by the International Ankle Consortium (Table 1)(Delahunt et al., 2010; Gribble et al., 2016, 2014a, 2014b, 2013). Before testing the participant provided written informed consent in accordance with the recommendations of the University Human Research Ethics Committee. The protocol for the experimental set-up required the participant to perform the following sports-related performance tests: (1) Change of Direction and Acceleration Test (Lockie et al., 2013) (2) Agility T-Test (Raya et al., 2013) (3) drop vertical jump (Doherty et al., 2014a). All performance tests were undertaken by the participant with and without an ankle brace (Aircast© A60). He wore the brace on his right ankle during the braced conditions, as it was deemed his most unstable ankle, as confirmed by his Cumberland Ankle Instability Tool (Hiller et al., 2006) scores. Accidentally, he experienced an episode of "giving way" of his non-braced, left ankle joint during his maximum effort "braced" right-sided Agility T-Test. Figure

1 describes the testing protocol. He was not injured during this “giving way” episode and was able to complete the test in 10.06 seconds. Upon completion of the Agility T-Test, he reported no symptoms of acute lateral ankle sprain injury such as pain, swelling or decreased weight-bearing status. He described the incidence as a typical “giving-way” episode. He was followed up 24 hours and one-week after the testing session and reported no acute lateral ankle sprain injury symptoms in his left ankle and had not had to restrict his participation in any physical activity.

Table 1: Athlete’s ankle injury characteristics and patient reported outcome scores

CAIT (Left Ankle)	23
CAIT (Right Ankle)	11
idFAI (Left Ankle)	18
idFAI (Right Ankle)	25
FAAM-ADL (Left Ankle)	67%
FAAM-ADL (Right Ankle)	60%
FAAM-Sport (Left Ankle)	56%
FAAM-Sport (Right Ankle)	53%
Number of Lateral Ankle Sprains (Left Ankle)	4+
Number of Lateral Ankle Sprains (Right Ankle)	5+

CAIT = Cumberland Ankle Instability Tool (Hiller et al., 2006); idFAI = Identification of Functional Ankle Instability Questionnaire (Gurav et al., 2014); FAAM-ADL = Foot and Ankle Ability Measure Activities of Daily Living (Carcia et al., 2008); FAAM-Sport = Foot and Ankle Ability Measure Sport (Carcia et al., 2008)

Lower Limb Movement Profiles Acquisition and Analysis

The ankle joint “giving way” episode was recorded on a Sony HDR-A15 video camera sampling at 120 Hz. The participant’s lower limb movement profiles were also simultaneously recorded by five Shimmer 3 inertial measurement units (IMUs) (Shimmer Research, Dublin, Ireland), sampling at 256 Hz; these were attached bilaterally to the participant’s feet, shanks and sacrum. Only signals from the left limb and back were analysed in this report. The tri-axial accelerometer and gyroscope signals were enabled and set to ranges of ±16 G and ±2,000 °/s, respectively. Accelerometer and gyroscope data were re-sampled to 240 Hz. Custom written code in MATLAB 2016b (The MathWorks, Natwick, USA) allowed for IMU and video camera data synchronisation. After synchronisation, initial contact of the "giving-way" episode was identified in the video sequence. A period of 200 ms pre-initial contact to 800 ms post-initial contact was extracted from all accelerometer and gyroscope signals for analysis. The same procedure of IMU data extraction was performed for the participant's non-braced maximum effort right-sided Agility T-Test, which was used as a non-injured comparison test.

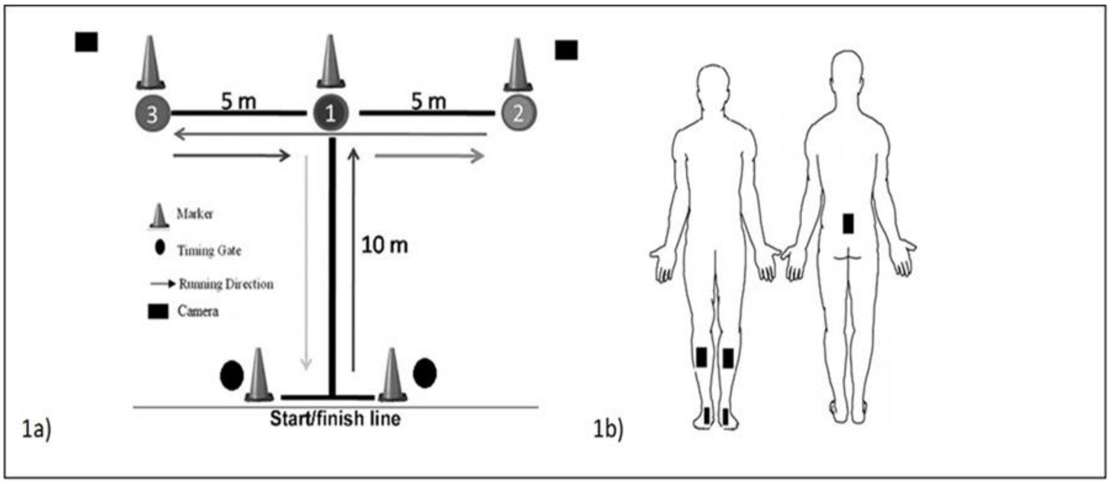

Figure 1: Testing Protocol (a) Agility T-Test Protocol (right-sided). Arrows indicate the direction the participant must run to complete the test. The test is initiated with a forward sprint to Cone 1, followed by lateral shuffle towards Cone 2, then a lateral shuffle across to Cone 3, followed by a lateral shuffle back to Cone 1, and ends with a back-pedal to the Start/Finish Line (b) Inertial Measurement Unit placement. Foot IMUs were secured under the participant's shoe laces at the midfoot on the dorsum of foot. Shank sensors were adhered 20 cm proximal to lateral malleolus anteriorly on the flattest segment of the shaft of the tibia with elastic adhesive bandage. The back sensor was mounted at the level of the fourth lumbar vertebra with straps provided with the IMUs.

Qualitative Video Analysis of the “Giving-way” Episode

Qualitative video analysis of the athlete’s performance of the Agility T-Test, including the epoch of the “giving-way” episode, was performed independently by three researchers (AR, CD and ED). Following completion of this initial step a consensus meeting was convened to agree upon the common features of the independent qualitative assessments. The full video can be viewed in the Supplementary Video file.

Results

Lower Limb Movement Profiles

Figure 2 and Figure 3 show the key shank and foot IMU signals of the “giving-way” episode, respectively, overlaid with the corresponding IMU signals for the non-injured comparison trial. An expanded description of the IMU signals is found in Appendix Table A1 (shank) and Appendix Table A2 (foot). The accidental “giving way” episode was characterised by plantar flexion of the ankle joint, as well as internal rotation and adduction of the ankle-foot complex, with peak rotational velocities reaching 797°/s, 1088°/s and 1734°/s, respectively. All other signal plots for the back, shank and foot sensors are provided in the Appendix Figures A1-A3.

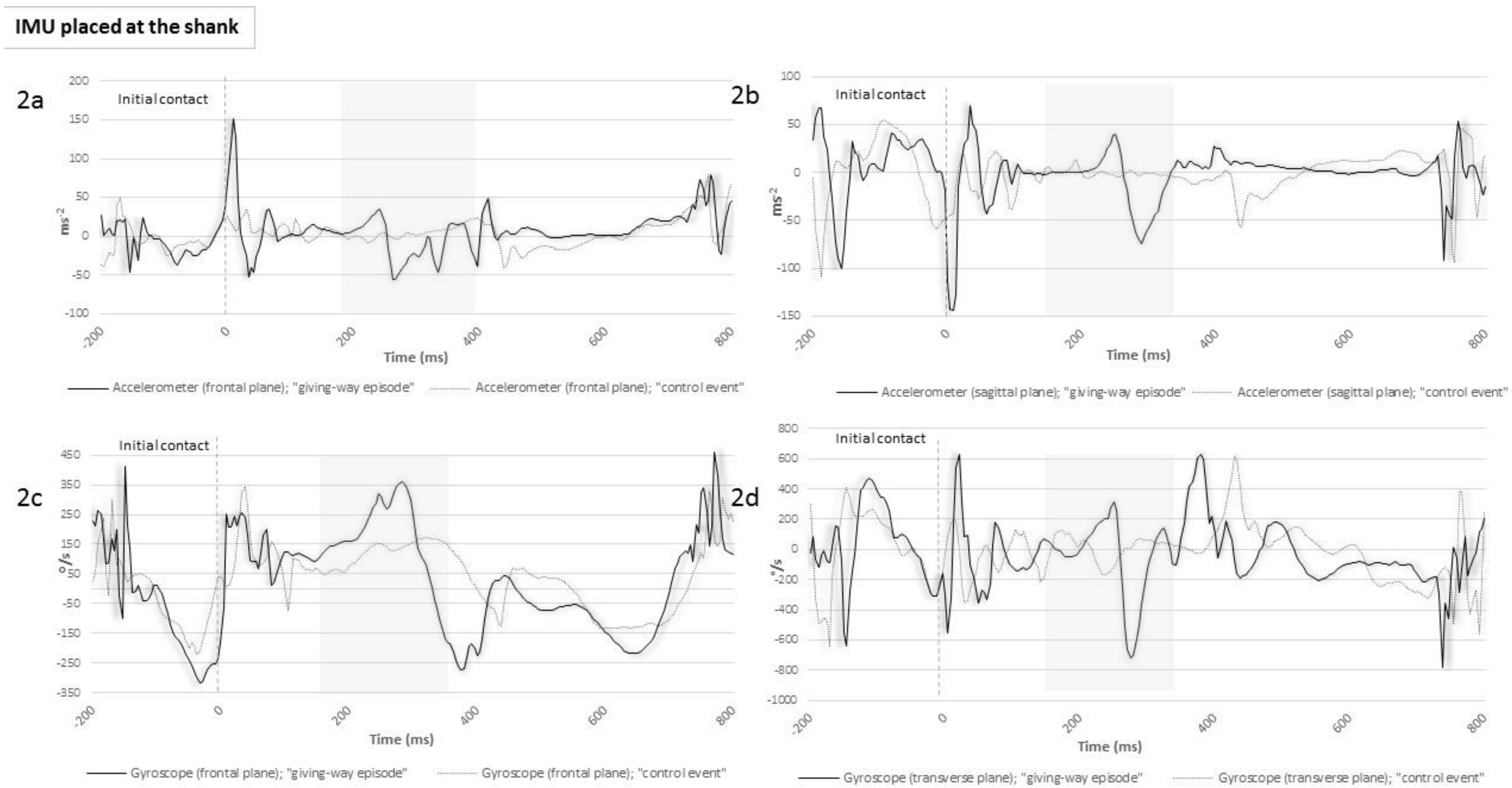

Figure 2: Shank IMU Kinematics

The rotational motion (gyroscope) and acceleration signals acquired using the IMU placed at the shank from 200ms pre- to 800ms post- the initial contact associated with the “giving way” episode (black line) and the matched non-injured comparison trial (dotted line). Initial contact is depicted using the light-grey vertical dashed line. The shaded grey area corresponds to an estimated area of the “giving way” episode.

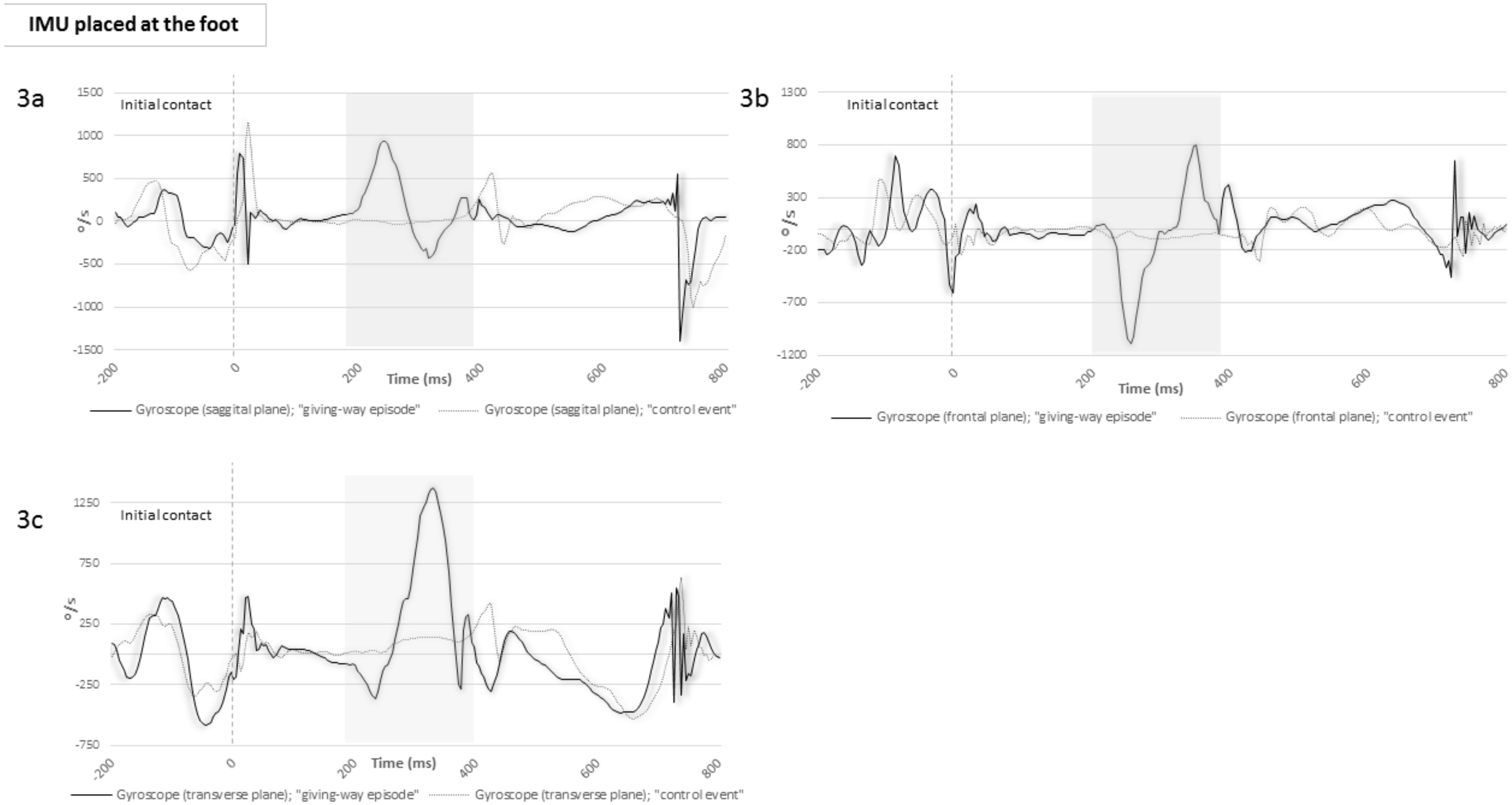

Figure 3: Foot IMU Kinematics

The rotational motion (gyroscope) signals acquired using the IMU placed at the foot from 200ms pre- to 800ms post- the initial contact associated with the “giving way” episode (black line) and the matched non-injured comparison trial (dotted line). Initial contact is depicted using the light-grey dashed vertical line. The shaded grey area corresponds to an estimated area of the “giving way” episode.

Qualitative Video Analysis

Nine key events of the Agility T-Test up to and including the "giving-way" episode are highlighted in Figure 4. An expanded description of the mechanism occurring in each of the key events is found in the supplemental Appendix Table A2.

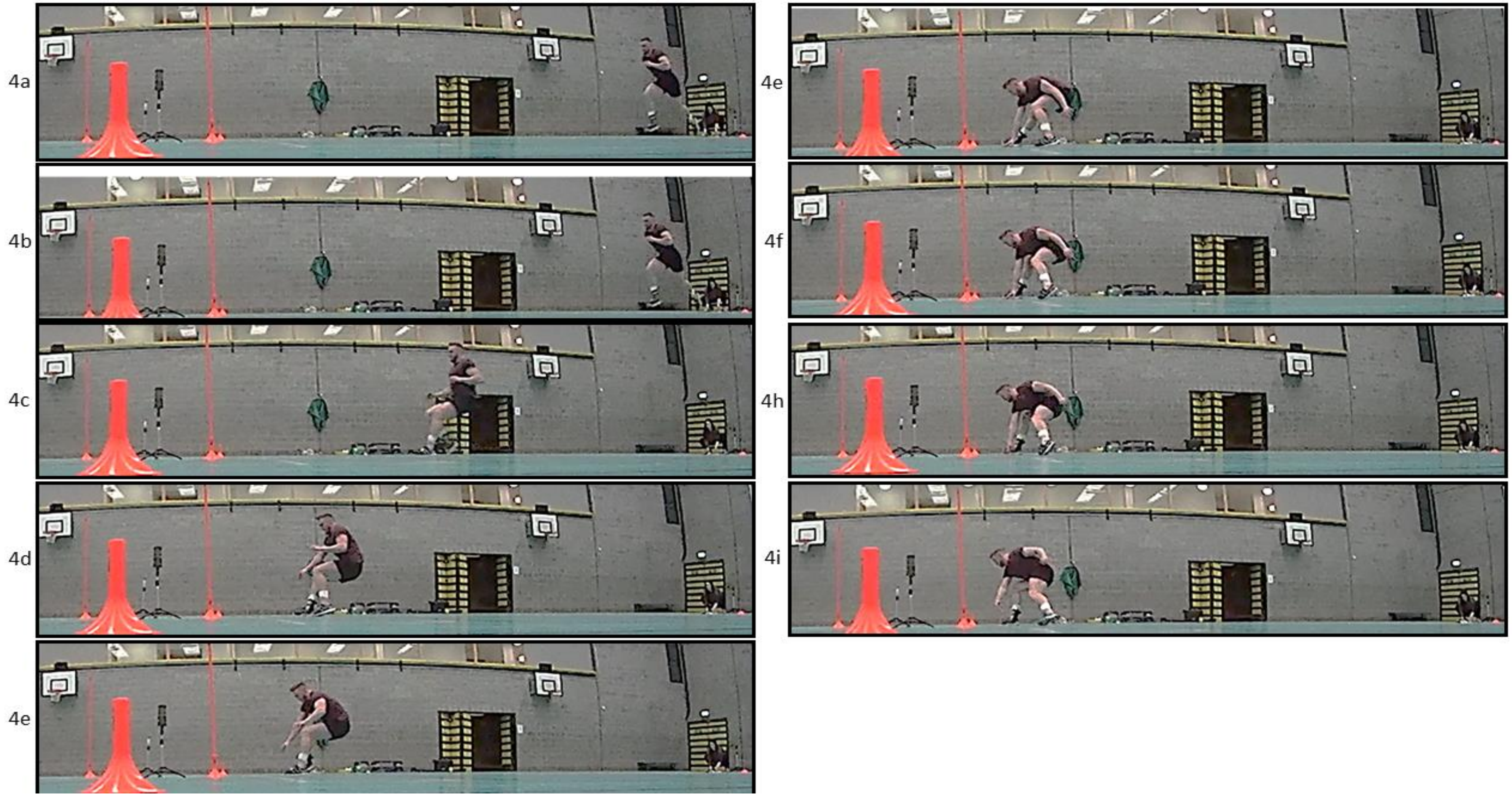

Figure 4: Video Analysis (a) Key Event 1: The Propulsive Phase; (b) Key Event 2: Running Gait; (c) Key Event 3: The Braking Phase; (d) Key Event 4: The "Slip"; (e) Key Event 5: Initiation of Change of Direction; (f) Key Event 6: Preparation of Change of Direction Phase; (g) Key Event 7: Change of Direction Propulsion Phase; (h) Key Event 8: The "Giving Way" Episode; (i) Key Event 9: The Reactive Phase

Discussion

To the knowledge of the authors, this brief report details the first instrument-based motion description of an episode of "giving-way" of the ankle joint incurred by a recreational athlete with CAI, whilst performing a change of direction task. This opportunistic dataset included linear acceleration and rotational velocities recorded from 5 IMUs, as well as high-definition video camera footage.

Nine key events were identified throughout the performance Agility T-Test, which were deemed integral to the mechanism of the "giving way" episode incurred by the athlete (Figure 4 and Appendix Table A2). Qualitative analysis identified that the "giving way" episode was characterised by plantar flexion of the ankle joint, as well as internal rotation and adduction of the ankle-foot complex. Evaluation of the IMU signals revealed high rotational velocities, comparable to those of previously published reports of lateral ankle sprain injury incidents (Andersen et al., 2004; Fong et al., 2012, 2009a, 2009b; Gehring et al., 2013; Kristianslund et al., 2011; Mok et al., 2011; Terada and Gribble, 2015). Following the "giving way" episode the participant utilised his right limb and trunk to "pull" his body mass towards the right, to continue the completion of the Agility T-Test (Key event 9; Figure 4i). He completed the Agility T-Test without any further identified movement aberrancies.

As part of the qualitative video analysis, the authors concluded that the "giving way" episode of the participant's left ankle was likely a manifestation of an aberrant braking strategy. Individuals with CAI have previously been reported to produce inefficient and altered braking forces during both planned and un-planned gait initiation and termination (Wikstrom et al., 2010; Wikstrom and Hass, 2012). Immediately prior to the "giving way" episode, the athlete experienced a forward "slip" of his left foot. The authors considered the slip on the left limb to have subsequently altered the next braking step on the right limb, subjecting the left limb to an uncontrolled foot placement during the next initial contact with the ground; ultimately culminating in the "giving way" episode. High frontal plane accelerations, which were absent in the non-injured comparison test at initial contact, were apparent in the IMU data of both the left foot and shank. These high accelerations likely represent excessive frontal plane motion of the left ankle. The apparent inefficiencies in the participant's braking strategy and the uncontrolled foot placement during the initial contact that preceded the "giving way" episode may be indicative of aberrant sensorimotor strategies for feedforward and/or feedback motor control.

The "giving way" episode experienced by the participant closely resembles the "classic" lateral ankle sprain injury mechanism. However, it remains unclear as to why the "giving way" episode did not manifest as an injury in the present instance, especially considering the similarity of the movement profile of the "giving-way" episode with previously documented lateral ankle sprain injury mechanisms (Andersen et al., 2004; Fong et al., 2012, 2009a, 2009b; Gehring et al., 2013; Kristianslund et al., 2011; Mok et al., 2011; Terada and Gribble, 2015). In the present study, the "giving way" episode was characterised by internal rotation with a peak internal rotation velocity of 1088°/s. This is comparable to previously captured internal rotation velocities during acute lateral ankle sprain injuries, which were found to be between 509 – 1752 °/s (Fong et al., 2012, 2009a; Gehring et al., 2013; Kristianslund et al., 2011; Mok et al., 2011). The "giving way" mechanism was also characterised by rapid adduction of the foot with a maximum adduction velocity of 1734 °/s. Additionally, the "giving way" mechanism was associated with a maximum plantar flexion velocity of 797 °/s; similar to the previously reported plantar flexion velocities of 325 – 1748 °/s captured during accidental lateral ankle sprain injuries involving a plantar flexion mechanism (Fong et al., 2012, 2009a; Gehring et al., 2013). With regards to the shank, during the "giving way" episode, a high external rotation velocity of 719°/s was recorded. The high internal rotation, adduction and plantar flexion rotational velocities were immediately followed by rapid external rotation, abduction and dorsiflexion rotational velocities in the concluding phase of the "giving way" episode. It is plausible that the rapid change of relative angular velocities at the concluding part of the "giving way" episode served to move the ankle-foot complex into a closed packed position, thus reducing the strain on the lateral ankle joint ligaments (Stormont et al., 1985).

The participant's apparent motor response to the "giving way" episode, namely, a pulling strategy employed by the right limb, may explain why no acute injury occurred. Specifically, simultaneous to the "giving way" episode on the left limb, the participant appeared to shift his body-mass to the right limb, which meant that although the participant's left foot was in a position vulnerable for lateral ankle sprain injury occurrence, it was unloaded (Andersen et al., 2004; Fong et al., 2012, 2009a, 2009b; Gehring et al., 2013; Kristianslund et al., 2011; Mok et al., 2011; Terada and Gribble, 2015). The absence of compressive load is most likely why an acute injury did not occur in this instance. Interestingly, upon completion of the test, the participant reported to the tester that he had been taught by a previous coach to *“shift my body mass to the contralateral side when I feel it starting to roll”*. It is plausible that the participant may have adopted this strategy in this instance. Following the unloading of the left foot-ankle, the athlete utilised a trunk dominant “pulling” strategy from the loaded right limb, instead of pushing off the “planted,” “giving way” left limb to begin the change of direction to the right cone. He completed the Agility T-Test without further incidence.

This study is not without limitation. Although we have attributed the “giving way” episode to an uncontrolled and inefficient braking strategy, the gym floor surface may not have been ideal and could have contributed to the “slip” and the “giving way” episode. However, the floor is representative of training and match conditions for all court sport athletes in our institution. Similarly, as participants were required to wear their own training shoes in this study, we could not control for shoe type and hence we could not control the coefficient of friction at the shoe-surface interface.

Conclusion

This study provides both a quantitative and qualitative description of a true “giving way” episode experienced by an individual with CAI. The episode was characterised by plantar flexion of the ankle joint, as well as internal rotation and adduction of the ankle-foot complex, with peak rotational velocities reaching 797°/s, 1088°/s and 1734°/s, respectively. This description provide a unique insight into the characteristic feature of “giving way” episodes experienced by individuals with CAI. The findings from this study could be utilised in the development of rehabilitation programmes and the design of protective equipment for individuals with chronic ankle instability.

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Conflicts of Interest

All authors of this article would like to state that there are no known conflicts of interest that could have biased or influenced the presented article.

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