

Case report

Biomechanics of ankle giving way: A case report of accidental ankle giving way during the drop landing test

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Abstract

Background: Several case studies observed that the lateral ankle sprain resulted from a sudden increase in ankle inversion accompanied by internal rotation. However, without sufficient ankle kinetics and muscle activity information in the literature, the detailed mechanism of ankle sprain is still unrevealed. The purpose of our case report is to present 2 accidental ankle giving way incidents for participants with chronic ankle instability (CAI) and compare to their normal trials with data of kinematics, kinetics, and electromyography (EMG).

Case description: Two young female participants accidentally experienced the ankle giving way when landing on a 25° lateral-tilted force plate. 3D kinematics, kinetics, and muscle activity were recorded for the lower extremity. Qualitative comparisons were made between the giving way trials and normal trials for joint angles, angular velocities, moments, centers of pressure and EMG linear envelopes.

Results: One participant's giving way trial displayed increased ankle inversion and internal rotation angles in the pre-landing phase and at initial contact compared to her normal trials. Another participant's giving way trial exhibited greater hip abduction angles and delayed activation of the peroneus longus muscle in the pre-landing phase versus her normal trials.

Conclusion: A vulnerable ankle position (i.e., more inverted and internally rotated), and a late activation of peroneus activity in the pre-landing phase could result in the ankle giving way or even sprains. A neutral ankle position and early activation of ankle evertors before landing may be helpful in preventing ankle sprains.

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Keywords: Chronic ankle instability; EMG; Kinematics; Kinetics; Lateral ankle sprain

1. Introduction

Lateral ankle sprain is one of the most common musculo-skeletal injuries during physical activity.^{1–3} Ankle sprains may lead to significant time loss from participation in sports, delayed return to play, and persistent disability in individuals who participate in sporting events.^{4,5} In addition, an initial lateral ankle sprain often causes repeated ankle sprains and results in chronic ankle instability (CAI).^{4,6} The symptoms of CAI consist of the sensation of “giving way”, perceived ankle instability, and repeated ankle rollover and sprains.^{7,8} “Giving way” has been defined by Gribble and colleagues⁹ as “the regular occurrence of uncontrolled and unpredictable episodes of

excessive inversion of the rear foot, which do not result in an acute lateral ankle sprain”.

The most common mechanism of a lateral ankle sprain has been attributed to excessive inversion with plantarflexion at the ankle joint.⁷ A limited number of previous case studies reported biomechanics of accidental ankle sprain incidences for individuals during cutting maneuvers,^{10–12} a jump landing task,¹³ a high jump event,¹⁴ a field hockey match,¹⁴ tennis competitions,¹⁵ and basketball games.¹⁶ All case studies suggested the lateral ankle sprain resulted from a sudden increase in ankle inversion accompanied by internal rotation. Gehring et al.¹² also observed a rapid ankle plantarflexion. In addition, a laterally shifted center of pressure (COP) was detected for the injury trial compared to other normal trials during the cutting maneuver because of the increased ankle inversion.^{10,11} Among the case studies, only one reported lower extremity kinetics

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and muscle activities.¹² However, without sufficient joint kinetics and muscle activity information in the literature, the detailed mechanism of ankle sprain is still unrevealed.

Therefore, the purpose of our case report is to present 2 accidental ankle giving way incidents for participants with CAI and compare to their normal trials with data of kinematics, kinetics, and electromyography (EMG). We also compare the variables listed above between the 2 giving way incidents to determine a common pattern or mechanism of giving way. Our report may provide valuable information to allow better understanding of the mechanisms of the ankle giving way and ankle sprain for individuals with CAI. It will also benefit the development of landing strategies and training programs to prevent ankle sprain injuries.

2. Case description

During our research study investigating drop landing biomechanics exhibited by individuals with CAI, unfortunately, 2 female participants accidentally experienced the ankle giving way when landing on a 25° lateral-tilted (inverted) force plate. The inclusionary (e.g., at least 1 significant ankle sprain and history of “giving way”, *etc.*) and exclusionary criteria (e.g., leg fracture or surgery, *etc.*) for CAI comprised previously published suggestions.¹⁷ One participant (P1) rolled over the ankle with a peak inversion angle of 55° after 9 normal trials; another (P2) rolled over with a peak inversion angle of 58° after 12 normal trials. The giving way trials were identified based on the 2 participants’ temporary uncontrollable sensation of instability and visual observation of ankle roll-over by investigators.¹⁸ Both participants quickly returned and controlled the ankle joint without losing balance or falls. Fortunately, no injury, pain or other symptoms occurred for either of the participants. Through follow-up contact with the participants 1 day after the incidents, both claimed that they had returned to full sports activities without any ankle problems. Participant characteristics are presented in Table 1.

A seven-camera Vicon system (Vicon Motion Systems Ltd., Oxford, UK) was used to capture spatial locations of 29 reflective markers placed on the trunk and lower body of the participants at 120 Hz (Fig. 1). Ground reaction forces (GRF) were collected using 2 Bertec force plates (Bertec Corp., Columbus, OH, USA) at 2040 Hz. The 2 force plates were side by side with one tilted downward 25° in the lateral direction (25° inverted surface) while the other one flat. The centers of the 2 force plates were at the same height. We used a tilted landing surface because landing on an inverted surface has been suggested as a more demanding situation.¹⁹ It is similar

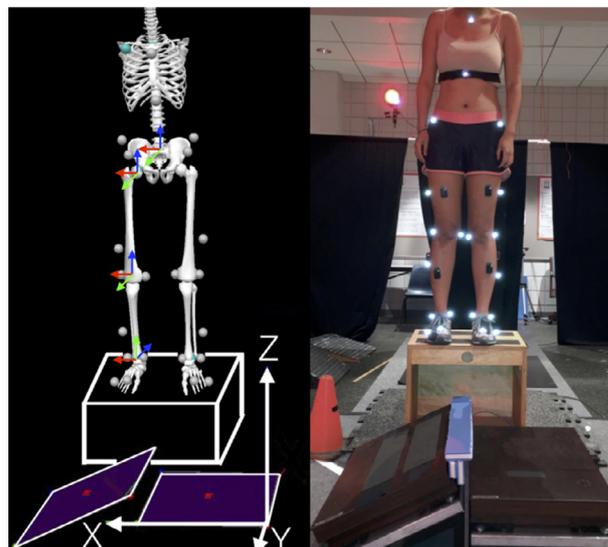


Fig. 1. Experimental setup.

to trail running on uneven surfaces, landing on another’s foot or even jogging on a tilted sidewalk. Tilted landing surfaces have been used in previous landing studies^{19–21} and even for participants with CAI.²² A wireless EMG system (sampling rate = 2040 Hz, Delsys Inc., Boston, MA, USA) was used to measure the ankle and hip muscle activations. Surface EMG electrodes were attached on the muscle belly of the anterior tibialis, peroneus longus, gastrocnemius lateralis, and tensor fascia latae on both limbs following the guidelines published previously.²³

The study was approved by the Institutional Review Board of the University of Georgia, and both participants provided written informed consent. Participants completed our proprietary health status and physical activity questionnaires. The Identification of Functional Ankle Instability (IdFAI) and Cumberland Ankle Instability Tool (CAIT) were used to assess ankle stability of both ankles. The limb with less ankle stability was chosen as the test limb. In order to normalize the EMG data, maximum voluntary isometric contraction (MVIC) tests were conducted for each muscle of the test limb using previously published procedures (see Ref.²⁴ for detailed procedures).^{25–27} Five-second MVIC EMG data for each muscle were collected.^{25,28} A 5-min warm-up session was performed before the drop landing test. For a given landing trial, participants stood on a box 30 cm high from the force plates. They then stepped forward with the test limb, followed by the other limb, and landed with the test foot on the tilted force plate and the other foot on the flat force plate. To ensure consistent performance, participants were not allowed to jump, hop, or step down from the box.²⁹ An investigator was standing close to the participants and ready to assist in the unlikely event that a participant began to lose balance during landings.

For each participant, the first 9 normal landing trials and 1 giving way trial were collected and analyzed. The phases of interest for analysis included the pre-landing and landing phases. The pre-landing phase was from 100 ms prior to contact (–100 ms) to the instant of initial contact (vertical GRF >

Table 1
Participants’ characteristics.

Participant ID	Height (cm)	Weight (kg)	Age (year)	IdFAI score	CAIT score	Test limb
P1	171	70	20	21	22	Right
P2	166	63	19	19	24	Left

Abbreviations: CAIT= Cumberland Ankle Instability Tool; IdFAI= Identification of Functional Ankle Instability.

10 N). The landing phase is from the initial contact to 200 ms after the contact (+200 ms). A 200-ms period was chosen because it covered the first instant when the center of mass reached its lowest height for all the trials and also the giving way incidences. Three-dimensional coordinates of the markers were reconstructed and filtered with a 4th order low-pass Butterworth filter at 15 Hz using Vicon Nexus 2.2 (Vicon Motion Systems Ltd.) based on the frequency analysis. Lower extremity segmental coordinate systems and joint centers were defined. The pelvis was constructed based on the previously developed model.³⁰ The thigh coordinate system was defined using hip joint center, knee joint center, and lateral thigh markers (Fig. 1). The shank coordinate system was determined using knee joint center, ankle joint center, and lateral shank markers. The foot coordinate system was built using the 2nd and 5th metatarsal head and heel markers. Joint angles (ankle and hip) and angular velocities were calculated using a Cardan sequence with order of X (extension/flexion), Y (adduction/abduction), and Z (internal/external rotation) (Visual 3D; C-Motion, Inc., Germantown, MD, USA). GRF were filtered with a 4th order low-pass Butterworth filter at 50 Hz based on frequency analyses. COP location (medial–lateral) relative to the ankle joint center was calculated in the foot coordinate system. Net internal joint moments at the ankle

were calculated using an inverse dynamic method and resolved in the proximal segment coordinate system.³¹ The segment masses, centers of mass, and radii of gyration were based on Hanavan's data.³² EMG data for each muscle were detrended and filtered at a 20–450 Hz band-pass frequency. Then the filtered EMG data were rectified and linear envelopes were generated (low-pass filter at 10 Hz);^{28,33} they were then normalized to the average value of the MVIC linear envelope of the corresponding muscle. To generate the ensemble average curve across 9 trials for each participant, kinematic, kinetic and EMG data were averaged, respectively. Qualitative comparisons were made between the giving way trials and normal trials. The significant difference was defined as the difference being greater than 1 standard deviation (SD) of normal trials.

3. Results

3.1. Kinematics

For the giving way trial of P1, compared to that exhibited in normal landing trials, the ankle was less inverted (5° – 6° vs. 7° – 9°) and internally rotated ($\sim 2^{\circ}$ vs. $\sim 5^{\circ}$) from about -100 ms to -50 ms. Then the ankle joint angles were comparable between the giving way and normal trials (difference <

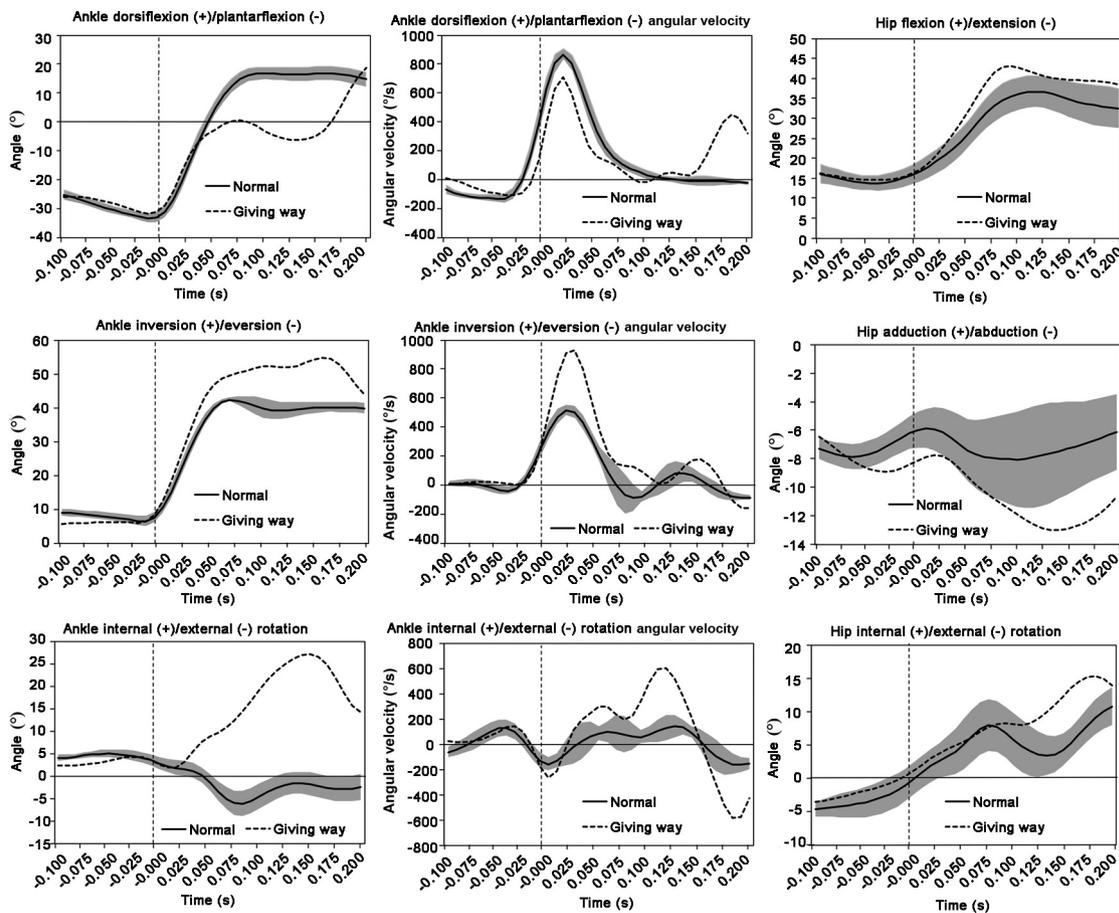


Fig. 2. Ankle joint angles (left column), angular velocities (middle column), and hip joint angles (right column) of P1 for the giving way trial and mean and standard deviation (shaded) of normal trials during the pre-landing and landing phases. Vertical dash line indicates initial contact.

2°) but with greater hip abduction angle (~9° vs. ~6°) from -50 ms until +15 ms in the giving way trial. A slightly reduced (26°–30° vs. 28°–32°) plantarflexion angle occurred from -60 ms to +25 ms. The apparent giving way seems to begin at about +25 ms, at which point the ankle exhibited less dorsiflexion, and greater inversion and internal rotation angle and inversion velocity. The peak inversion angle in the giving way trial was 55°, about 13° greater than that in normal trials. The peak internal rotation angle was 27°, while the ankle mostly externally rotated in the landing phase of normal trials. The peak inversion velocity was also greater in the giving way trial (927°/s vs. 528°/s). In general, the hip joint exhibited greater flexion, abduction, and internal rotation during the landing phase compared to normal trials (Fig. 2).

For P2, the plantarflexion angles were comparable (~40°, difference < 2°) among trials in the pre-landing phase and until -10 ms. For the giving way trial, a slightly reduced ankle plantarflexion angle displayed from -10 ms to +20 ms versus the normal trials. Greater ankle inversion (13°–17° vs. 10°–12°) and ankle internal rotation (~10° vs. 2°–7°) and less hip abduction (3°–5° vs. 6°–7°) angles were observed during the pre-landing phase. The giving way started as soon as P2 contacted the ground. The peak values of giving way were greater

for inversion angles (58° vs. 37°), internal rotation angles (49° vs. 2°) and inversion velocities (647°/s vs. 450°/s). Moreover, a significant increase of hip internal rotation and adduction was observed in the giving way trial, starting at +110 ms and +150 ms, respectively (Fig. 3).

In general, the 2 participants exhibited similar ankle and hip joint angles during normal drop landings and reached peak inversion velocities at about +25 ms in the giving way; however, the joint angles in the pre-landing phase were different between the 2 giving way trials. The major differences in ankle joint angles occurred in the frontal and transverse planes. P1 exhibited less ankle inversion and external rotation from -100 ms to -50 ms compared to her normal trials, whereas P2 displayed greater ankle inversion and internal rotation throughout the pre-landing phase. Hip joint angles also suggested different patterns in the frontal and transverse planes between the 2 giving way trials.

3.2. Kinetics

For P1, the most notable difference in joint moment is the ankle external rotation moment in the landing phase. At about +20 ms, the external rotation moment of the giving way trial

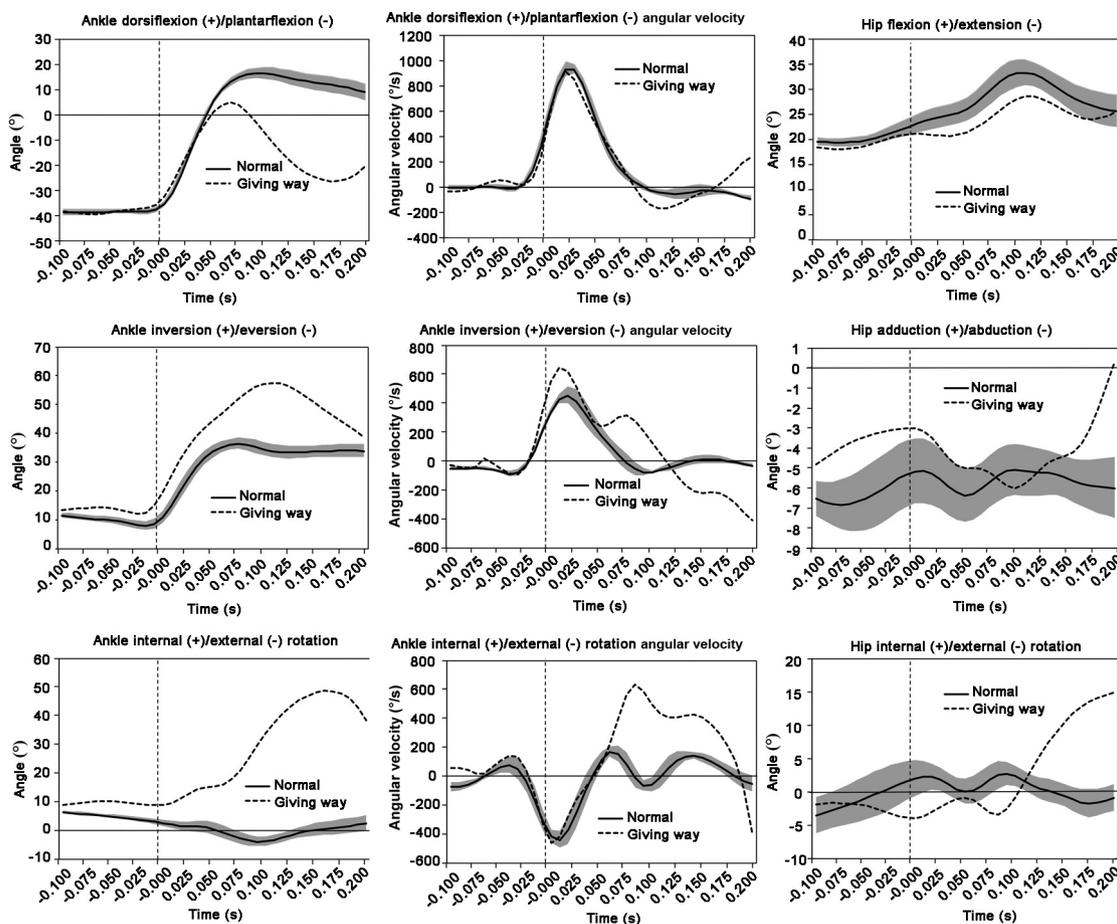


Fig. 3. Ankle joint angles (left column), angular velocities (middle column), and hip joint angles (right column) of P2 for the giving way trial and mean and standard deviation (shaded) of normal trials during the pre-landing and landing phases. Vertical dash line indicates initial contact.

quickly reduced until +45 ms, then continuously increased until +175 ms. In general, the external rotation moment of normal trials increased from the instant of contact to about +75 ms, then reduced through the rest of the landing phase (Fig. 4A).

For P2, the notable differences in the landing phase occurred in the ankle eversion and external rotation moment (Fig. 4B). The ankle exhibited a greater eversion moment from +5 ms to +175 ms and a greater external rotation moment from 0 to +30 ms for the giving way trial versus the normal trials. In addition, a quick reduction in ankle external rotation moment was also observed from +25 to +45 ms in the giving way trial (Fig. 4B).

In the landing phase, both participants exhibited a quickly reduced ankle external rotation moment from about +15 ms to +45 ms in the giving way trials. Both giving way trials displayed a significant lateral shift of the COP compared to normal trials. The COP was more lateral, starting at +15 ms for P1 and at 0 ms (initial contact) for P2 during the giving way trials, respectively (Fig. 4).

3.3. EMG

For P1, muscle activations displayed similar patterns between the giving way and normal trials in the pre-landing phase, with the exception of a reduced gastrocnemius lateralis activation (from -55 ms to -20 ms) and a reduced peroneus longus activation (from -100 ms to -45 ms) in the giving way trial. Several muscle activations displayed differences in the landing phase. Compared to normal trials, the gastrocnemius lateralis exhibited greater peak activation in the giving way trial. In addition, peak muscle activation in the landing phase of the giving way trial occurred about 20 ms earlier for the gastrocnemius lateralis, peroneus longus, and tensor fascia latae (Fig. 5A).

For P2, earlier deactivations were observed for the peroneus longus and gastrocnemius lateralis in the giving way trial during the pre-landing phase. Earlier activation patterns and peaks were found for the anterior tibialis, gastrocnemius lateralis, and tensor fascia latae in the landing phase of the giving way trial. In addition, the anterior tibialis and tensor fascia latae exhibited significant greater peak activations in the giving way trial (Fig. 5B).

In general, muscle activations were comparable between the 2 giving way trials. The only major difference was that P1 exhibited delayed onset of peroneus longus activation in the pre-landing phase compared to that of P2 and P1's normal trials (Fig. 5).

4. Discussion

4.1. Kinematics

The joint angle differences between the 2 giving way trials may suggest 2 different mechanisms of an ankle giving way or a sprain occurring when landing on the tilted surface. First, giving way could occur due to greater ankle inversion and internal rotation angles during the pre-landing phase and at

initial contact (e.g., P2), because the ankle was in a less stable position.^{34,35} Second, giving way could happen even with typical ankle joint angles at initial contact along with delayed peroneus pre-activation (e.g., P1, described later in the EMG section). Moreover, an increased hip abduction was observed at initial contact and 50 ms before that for P1. Though hip joint kinematics may not associate with mechanisms of CAI,³⁶ the increased hip abduction in the giving way trial may contribute to maintaining the ankle inversion angle within the typical range of normal trials. However, this hip adjustment could accidentally create unexpected sensations in other joints (e.g., knee and ankle) or unanticipated timing of ground contact and resulted in the giving way incident, similar to that in the sprain injury reported by Gehring et al.¹²

In the landing phase, both giving way incidents displayed greater ankle plantarflexion, inversion and internal rotation angles compared to normal trials. Through viewing the animations of ankle movement in Visual 3D software (C-Motion, Inc.), both incidents occurred with the forefoot contacting the ground while the rearfoot drifted laterally. This pattern of ankle kinematics was in agreement with Fong et al.¹⁰ They reported a 48° maximum inversion angle in the injury trial. Fortunately, even with greater (7° and 10°, respectively) maximum inversion angles, our participants did not injure the ankle, possibly because they anticipated landing on the tilted surface with a great amount of ankle inversion angle. In addition, increased hip internal rotation in the late stage of the landing phase (from +125 ms and +110 ms for P1 and P2, respectively) could reduce the ankle internal rotation angle to prevent excessive strain on the lateral ankle.

4.2. Kinetics

In the landing phase, interestingly, both participants exhibited a quickly reduced ankle external rotation moment from about +15 ms to +45 ms. However, the purpose or the mechanism of this reduced moment is still unclear. One potential explanation could be the effect or reaction of the “sudden explosive torque” of the ground reaction force due to the increased moment arm when the foot internally rotating.¹⁰ To prevent further ankle inversion in the giving way trials, the participants exhibited different strategies: P1 increased the peak peroneus longus activation to control the ankle inversion angle (described in the following section), whereas P2 increased the ankle eversion moment to reduce the inversion angle starting from +100 ms.

The COP shifted laterally for all trials in the landing phase. However, the COP location was more lateral in the giving way trials, which corresponded with the results of previous studies.^{10,11} It has been suggested that a laterally shifted COP may place the ankle at a high risk of lateral sprain.^{10,37} Moreover, a more lateral COP of P2 at initial contact in the giving way trial corresponded with the greater ankle inversion angle. Therefore, the ankle was at a high risk of injury and thus gave way.

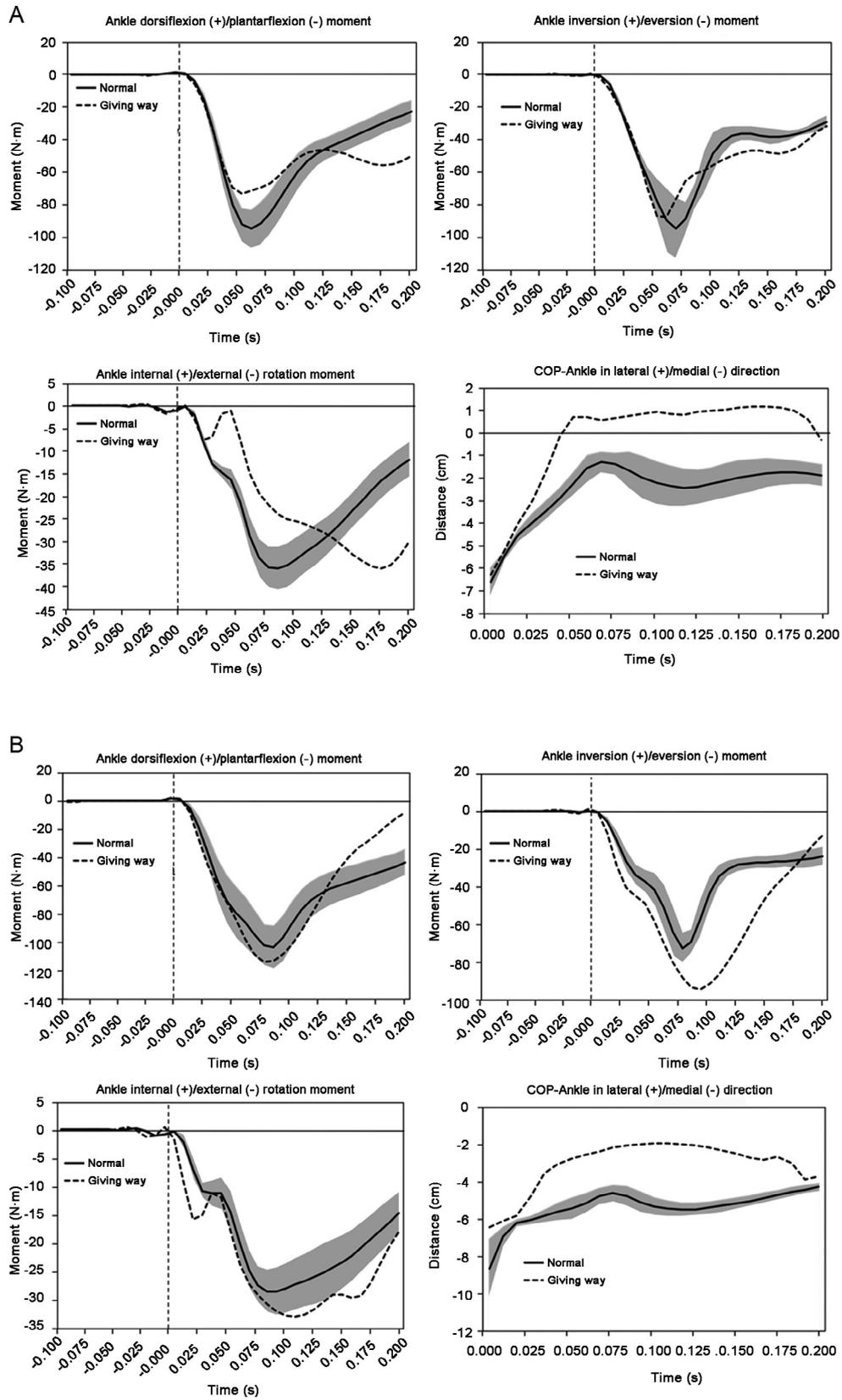


Fig. 4. Ankle net joint moment and center of pressure (COP) location relative to the ankle joint center in lateral(+)/medial(-) direction of P1 (A) and P2 (B) for the giving way trial and mean and standard deviation (shaded) of normal trials during the pre-landing and landing phases. COP location (medial-lateral) relative to the ankle joint center was calculated in the foot coordinate system. The vertical dash line indicates initial contact.

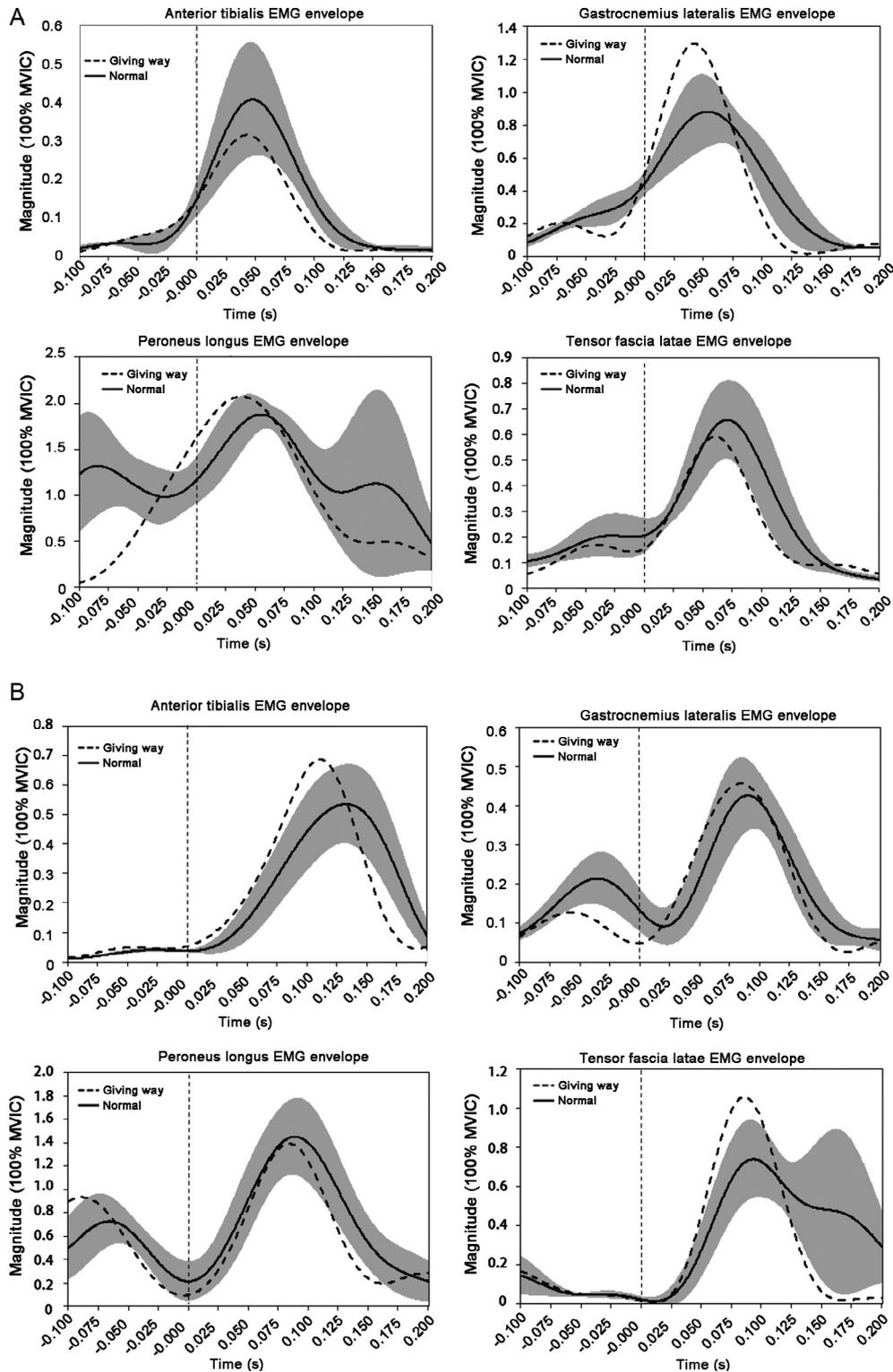


Fig. 5. Lower extremity muscle activation (linear envelope) of P1 (A) and P2 (B) for the giving way trial and mean and standard deviation (shaded) of normal trials during the pre-landing and landing phases. Vertical dash line indicates initial contact. EMG= electromyography; MVIC = maximum voluntary isometric contraction.

4.3. EMG

The general patterns of muscle activities were similar between the giving way trials and the normal trials of both participants, with the exception of the peroneus longus activation

in the giving way trial of P1. A delayed onset of peroneus longus activation was observed in the pre-landing phase, which has been associated with ankle instability³⁸ and risk of ankle sprain.¹⁰ As it is an ankle evtor muscle, peroneus longus activity could affect the ankle inversion/eversion angle.

Delahunt et al.³⁴ reported reduced peroneus longus activity accompanied by an increased ankle inversion for CAI participants compared to healthy controls during pre-landing. In the present study, we did not find the association between peroneus longus activity and ankle inversion angle possibly because of different landing protocols. Peroneus longus activity in the pre-landing phase has been suggested to provide joint stability and prevent inversion injuries.³⁹ Therefore, the delayed peroneus longus activation of P1 could relate to the mechanism of giving way. However, there is no evident difference in the peroneus longus activation amplitude, but an earlier deactivation in pre-landing was observed for the giving way trial of P2. This earlier peroneus longus deactivation along with increased ankle inversion and internal rotation could be the factors that resulted in the giving way for P2. Both participants displayed earlier gastrocnemius lateralis deactivation in the giving way trials, which may correspond with the slightly reduced ankle plantarflexion angle in the pre-landing phase. However, whether this minor difference in plantarflexion could relate to the mechanism of the ankle giving way still needs to be confirmed by future studies.

In the landing phase, different muscle activities between the giving way trials may indicate different strategies to control ankle inversion angle and prevent sprain injuries. An earlier and greater peak peroneus longus activity compared to normal trials could be used to prevent excessive ankle inversion angle for P1. For P2, no significant difference was found for peroneus longus activities. However, greater anterior tibialis and tensor fascia latae activation of P2 may contribute to increasing ankle stability and controlling leg orientation in the frontal plane, respectively.

4.4. Limitation

The first limitation of the present report is the marker placement on the shoes. It is possible that there is some relative motion between the shoes and feet, which potentially affects the accuracy of foot/ankle biomechanics. Landing on a tilted surface may be a unique situation; therefore, the findings in the present report may not be applied to flat surface landings. In addition, joint moments in the pre-landing phase presented in Fig. 4 should be used or interpreted with caution. Small sample size is also an issue. Only 2 females were included, and thus the findings can only be applied to females but not males.

5. Conclusion

The present report provided lower extremity kinematics, kinetics, and EMG of individuals with CAI for 2 giving way incidents during drop landings onto a tilted surface. Two different giving way mechanisms were observed, which suggested that a poor ankle position (i.e., more inverted and internally rotated) and a late activation of peroneus activity during the pre-landing phase could result in the ankle giving way or even sprains. Training programs that improve peroneus longus muscle strength and activation, as well as ankle proprioception, especially in the inversion/eversion direction, could be

beneficial for individuals with CAI in preventing recurrences of the ankle giving way or sprains during sports activities.

Authors' contributions

YL contributed to research idea development, study design, data collection, data analysis, and manuscript writing; JK contributed to research idea development and study design; SZ contributed to data analysis and manuscript editing; CNB contributed to study design and manuscript editing; KJS contributed to study design and manuscript editing. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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