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Anticipating ankle inversion perturbations during a single-leg drop landing alters ankle joint and impact kinetics

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ABSTRACT

Anticipatory responses to inversion perturbations can prevent an accurate assessment of lateral ankle sprain mechanics when using injury simulations. Despite recent evidence of the anticipatory motor control strategies utilized during inversion perturbations, kinetic compensations during anticipated inversion perturbations are currently unknown. The purpose of this investigation was to examine the influence of anticipation to an inversion perturbation during a single-leg drop landing on ankle joint and impact kinetics. Fifteen young adults with no lateral ankle sprain history completed unanticipated and anticipated single-leg drop landings onto a 25° laterally inclined platform from a height of 30 cm. One-dimensional statistical parametric mapping (SPM) was used to analyze net ankle moments and ground reaction forces (GRF) during the first 150 ms post-landing, while peak GRFs, time to peak GRF, peak and average loading rates were compared using a dependent samples *t*-test ($p \leq 0.05$). Results from the SPM analysis revealed significantly greater plantar flexion moment from 58 to 83 ms post-landing ($p = 0.004$; $d = 0.64$–0.77), inversion moment from 89 to 91 ms post-landing ($p = 0.050$; $d = 0.58$–0.60), and medial GRF from 62 to 97 ms post-landing ($p < 0.001$; $d = 1.00$–2.39) during the unanticipated landing condition. Moreover, significantly greater peak plantarflexion ($p < 0.001$; $d = 1.10$) and peak inversion moment ($p = 0.007$; $d = 0.94$), as well as greater peak ($p = 0.002$; $d = 1.03$) and average ($p = 0.042$; $d = 0.66$) medial loading rates, were found during the unanticipated landing condition. Our findings suggest alterations to ankle joint and impact kinetics occur during a single-leg drop landing when inversion perturbations are anticipated. Researchers and practitioners using drop-landings onto a tilted surface to assess lateral ankle sprain injury risk should consider implementing protocols that mitigate anticipatory responses.

1. Introduction

Ankle sprains, specifically those that damage the lateral ankle ligaments, are the most common injury sustained in high school (Fernandez, Yard, & Comstock, 2007) and college sports (Roos et al., 2017). Lateral ankle sprains are often viewed as trivial injuries

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that do not require medical treatment and/or rehabilitation, but in fact, this injury has a poor prognosis with approximately 70% of individuals encountering recurrent injuries (van Rijn et al., 2008; Yeung, Chan, So, & Yuan, 1994), substantial time lost (≥3 weeks) from sport participation (Roos et al., 2017), and a plethora of long-lasting sensorimotor and mechanical deficits (Hertel, 2008). Jump-landing based sports such as basketball, volleyball, and soccer have been reported to have the highest rates of lateral ankle sprain injury, with roughly half of these injuries occurring from a non-contact mechanism (Hootman, Dick, & Agel, 2007; Roos et al., 2017). This highlights the need to conduct injury risk assessments in populations performing jump-landings to identify movement mechanics that contribute to an increased risk of a lateral ankle sprain injury.

Lateral ankle sprains are a consequence of unanticipated and excessive inversion, internal rotation and plantar flexion of the ankle joint complex on an externally rotated distal tibia (Fong et al., 2009; Terada & Gribble, 2015). Although several case reports of lateral ankle sprain injuries have been published (Fong et al., 2009; Fong, Ha, Mok, Chan, & Chan, 2012; Gehring, Wissler, Mornieux, & Gollhofer, 2013; Kristianslund, Bahr, & Krosshaug, 2011; Terada & Gribble, 2015), injury simulations are widely used in laboratory research to safely replicate real-time injury mechanisms to study lateral ankle sprain mechanics in many paradigms (Ha, Fong, & Chan, 2015). Laterally inclined platforms (Sato, Nunome, Hopper, & Ikegami, 2017; Simpson et al., 2018) and an outer sole with fulcrum (Knight & Weimar, 2011, 2012; Simpson, DeBusk, Hill, Knight, & Chander, 2017) are commonly used devices that create forced inversion of the ankle joint complex during drop landings on one foot, a common sporting maneuver that can result in a lateral ankle sprain injury (Terada & Gribble, 2015). Implementing these devices in laboratory investigations allows for an assessment of lower extremity movement dynamics to identify underlying factors that contribute to an increased risk of a lateral ankle sprain injury when landing on one foot. However, rapid inversion of the ankle joint complex experienced during a lateral ankle sprain injury is one factor that is difficult to reproduce using injury simulations in laboratory investigations (Dicus & Seegmiller, 2012; Simpson et al., 2018).

Anticipatory responses to inversion perturbations pose a considerable challenge when using injury simulations in a laboratory research, and recent evidence suggests that anticipating inversion perturbations result in significant alterations to lower extremity movement dynamics (Dicus & Seegmiller, 2012; Gehring, Wissler, Lohrer, Nauck, & Gollhofer, 2014; Simpson et al., 2018, 2019). Specifically, a hip dominant landing strategy (Simpson et al., 2018), increased fibularis longus amplitude and ankle frontal plane muscular co-contraction (Dicus & Seegmiller, 2012; Gutierrez et al., 2012; Simpson et al., 2019), reduced ankle frontal plane displacement and velocity have been observed during anticipated ankle inversion perturbations (Gehring et al., 2014; Simpson et al., 2018). These changes in anticipation to injurious perturbations can confound biomechanical outcomes when approximating the supination moment experienced during a lateral ankle sprain injury. Therefore, implementing experimental protocols that mitigate anticipatory responses and encompass sport specific movements are warranted to more closely approximate real-time injury mechanisms (Dicus & Seegmiller, 2012; Simpson et al., 2018).

Although prior investigations provide initial insight to the lower extremity kinematic and neuromuscular alterations that occur in anticipation to inversion perturbations during single-leg drop landings (Dicus & Seegmiller, 2012; Simpson et al., 2018, 2019), less is known regarding the influence of anticipation to an inversion perturbation on ankle joint and impact kinetics. Assessing ankle joint and impact kinetics that occur during anticipated inversion perturbations will provide further insight regarding anticipatory mechanisms and assist in modifying existing experimental protocols to mitigate anticipatory responses. Furthermore, this would allow for accurate biomechanical data to be obtained when using injury simulations to identify the potential underlying factors that contribute to the lateral ankle sprain injury paradigm. The purpose of this investigation was to analyze ankle joint and impact kinetics during unanticipated and anticipated landings onto an inverted surface utilizing a new experimental protocol that has been shown to approximate the mechanism of a lateral ankle sprain during a single-leg drop landing (Simpson et al., 2018). While altered neuromuscular control and lower extremity kinematics have been observed during anticipated inversion perturbations (Dicus & Seegmiller, 2012; Gehring et al., 2014; Simpson et al., 2018, 2019), we hypothesized ankle joint and impact kinetics would be significantly greater during the unanticipated landing on the laterally inclined surface compared to the anticipated landing.

2. Methods

2.1. Participants

An *a priori* power analysis (G-Power software, Dusseldorf, Germany) was conducted ($\beta = 0.80$, $\alpha = 0.05$), which was based on an average effect size of 0.50 that was observed in a previous study examining unanticipated and anticipated inversion perturbations (Simpson et al., 2018), and determined that 15 participants would be needed. Therefore, fifteen young adults (8 male, 7 female; age: 20.9 ± 1.3 y; height 1.7 ± 0.1 m; mass: 69.3 ± 10.7 kg) were recruited and volunteered to participate in the study. Participants were eligible to participate in the study if they met all of the following criteria: (i) physically active at least 30 min per day, 3 or more days per week; (ii) currently participating in recreational or competitive sports; (iii) have no self-reported history of any lower extremity musculoskeletal injury or surgery; (iv) score 100% on the Foot and Ankle Disability Index (FADI) and the Foot and Ankle Disability Index-Sport (FADI-S) questionnaires. Prior to participating, participants were required to read and sign an informed consent document that outlined the possible risks and procedures of the study. All study procedures were approved by the Institutional Review Board at the authors' university prior to initiating data collection procedures.

2.2. Instrumentation

A 3-dimentional motion analysis system equipped with 12 Bonita 10 infra-red cameras (Vicon, Oxford, UK) was used to collect

Fig. 1. Retro-reflective cluster placement on the participants.

kinematic data at 100 Hz. Retro-reflective marker sets were placed bilaterally on the dorsal foot and shank. Double sided tape was used to attach the cluster sets while nylon wraps with velcro straps were placed around the cluster sets to reduce marker movement artifact (Fig. 1). The ankle joint center was estimated using the centroid method in the MotionMonitor software (Innovative Sports Training, Inc., Chicago, IL, USA) by placing a measurement sensor on the medial and lateral femoral condyles, medial and lateral malleoli, and the second distal phalanx (Simpson et al., 2018). The same investigator placed the measurement sensor on each participants' prominent anatomical landmarks to construct the foot and ankle segments to determine the ankle joint center in the software.

An AMTI AccuGait (Watertown, MA, USA) force platform recording at 1000 Hz was embedded on a flat and laterally inclined platform. Both the flat and laterally inclined platforms were constructed to ensure a consistent 30 cm landing height from the center of the force platform (Fig. 2). The laterally inclined platform was tilted 25° in the frontal plane, which was chosen for participant safety, to produce an inversion perturbation subsequent to landing from a height of 30 cm. Grip tape was applied to the top of the force platform to prevent the participants' foot from slipping during the drop-landing task (described below). The design of the platforms was adopted from recent literature using a tilted surface to produce an inversion perturbation during a single-leg drop landing (Sato et al., 2017; Simpson et al., 2018). The ankle kinematic and ground reaction force (GRF) data was collected and time-synchronized with the MotionMonitor software.

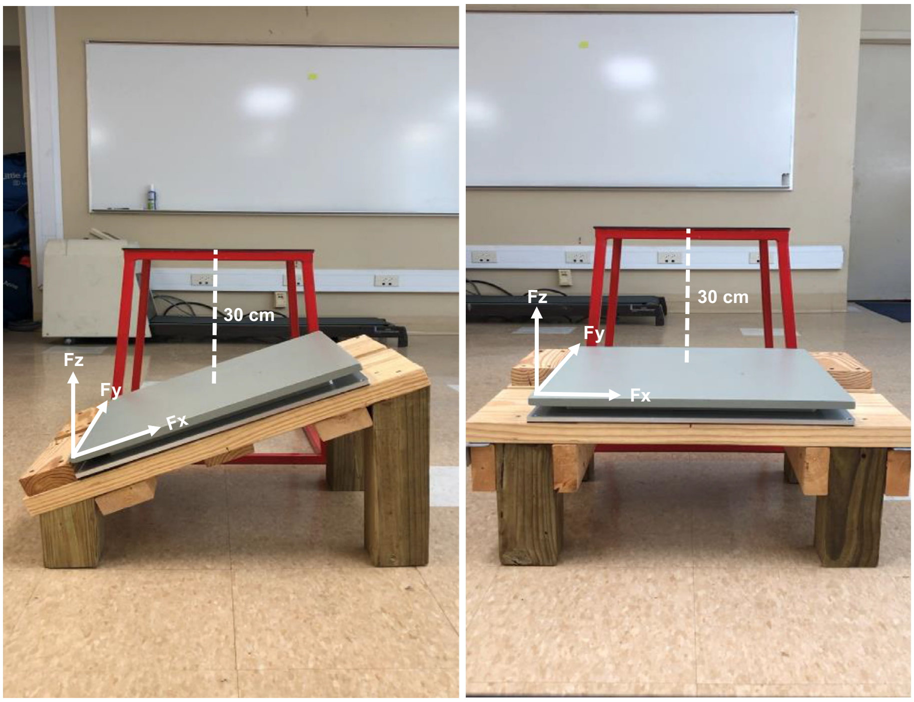

Fig. 2. The laterally inclined (left) and flat (right) platforms.

2.3. Protocol

Each participant was required to complete a total of two testing sessions. The first session was a familiarization session in which the FADI and FADI-S surveys were completed, height and mass were recorded using a physician's scale (Tanita Corporation, Tokyo, Japan) and a stadiometer (Webb City, MO, USA), respectively. Limb preference was also determined by participants reporting which leg they would use to kick a ball (Niu, Wang, He, Fan, & Zhao, 2011). After completion of required documents and anthropometric measurements, participants were provided with detailed information regarding the procedures that would be implemented during the experimental session. Furthermore, participants were permitted to practice the drop landing task onto the flat surface as many times as desired. Although participants were made aware, both verbally and in the written informed consent document of the laterally inclined platform that would be used in the study, participants were not allowed to visually see the laterally inclined platform to further reduce any anticipatory responses during their experimental testing session.

Following completion of the familiarization session, participants returned within 48–72 h in the same low-top athletic shoe to complete their experimental testing session. Each testing session began with participants completing a total of 5–10 drop landings that were not recorded onto the flat platform to establish a normal drop landing movement pattern. To create visual obstruction of the participants' feet a 55 cm × 55 cm pad was held against the waist at the level of the navel for all drop landing trials. The drop landing task used in this study required participants to stand on their non-preferred limb with their preferred limb relaxed and held slightly anterior to the edge of a box that was raised 30 cm above the landing surface. Then, participants stepped forward off the edge of the box, landed on the platform with their preferred limb, and then immediately took another step down to the ground and landed on their non-preferred limb (Simpson et al., 2018, 2019). After completion of the initial practice trials, 5 more drop landing trials onto the flat surface were completed and recorded. Then, participants were turned away from the testing area and listened to music being played on noise-cancellation headphones for 60 s to take away the knowledge of the upcoming drop landing trials on either the flat or laterally inclined surfaces.

A maximum of 10 more trials were completed of the drop landing task onto the flat surface with music being played for 60 s between trials. However, one trial was randomly selected without the participants' knowledge to use the laterally inclined platform in place of the flat platform and treated as the unanticipated inversion perturbation. This trial was randomly chosen using the randomize function in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Each participant was then asked to subjectively report their level of anticipation to the laterally inclined platform after their unanticipated trial, and all participants subjectively reported they were not expecting the laterally inclined platform during their respective trial. To further reduce anticipation, trial 1 and 10 were excluded from being chosen to use the laterally inclined platform. Then, a 60 s break was given while the laterally inclined platform was re-adjusted and then participants were asked to complete the drop landing task onto the laterally inclined platform one final time. For this final trial participants were given verbal instruction that they would be "landing on the tilted surface", and this trial was considered the anticipated inversion perturbation. Only the preferred limb was tested during the drop landing task in this study.

2.4. Data analysis

2.4.1. Joint moments

Ankle kinematics were computed using the Grood-Suntay angle orientation method (Grood & Suntay, 1983). The distal shank served as the reference point for all ankle kinematic data, which was filtered with a low-pass third-order Butterworth filter using a cutoff frequency 15 Hz prior to being extrapolated to force platform data. Net ankle moments in the sagittal, frontal and transverse plane were then computed from the time-synchronized ankle kinematic, GRF and anthropometric data using an inverse dynamics procedure in the MotionMonitor software and normalized to body mass (Nm/kg) for each participant. Ankle moments were analyzed during the first 150 ms after initial foot contact on the force platform (Caulfield & Garrett, 2004; Doherty et al., 2016), which was determined using a vertical GRF threshold of 15 N. Additionally, discrete parameters of peak sagittal, frontal, and transverse plane ankle moment were also obtained and identified as the maximum moment during the first 150 ms after landing (Koshino et al., 2017). The time window of 150 ms after initial foot contact was chosen for analysis as previously published case reports indicate lateral ankle sprains occur within the first 150 ms of initial ground contact (Kristianslund et al., 2011; Terada & Gribble, 2015).

2.4.2. Impact kinetics

Ground reaction forces were also analyzed during the first 150 ms post-landing. The force platform was set up in the software to record positive (+) values in the vertical, medial, and posterior directions. Force-time data during the first 150 ms post-landing was also used to determine the following impact kinetic parameters: (i) peak vertical, medial, and posterior GRF was identified as the absolute peak vertical, medial, and posterior GRF during the first 150 ms after initial contact; (ii) time to peak vertical, medial, and posterior GRF was identified as the time in milliseconds (ms) to reach the absolute peak vertical, medial, and posterior GRF; (iii) average vertical, medial, and posterior loading rates were calculated by dividing the absolute peak GRF by the total time to reach the absolute peak GRF; and (iv) peak vertical, medial, and posterior loading rates were identified as the greatest loading rate at any time point from initial contact on the force platform until peak vertical, medial, and posterior GRF was reached (Stewart, Kernozek, Peng, & Wallace, 2018). All GRF data was then normalized to each participants' body weight (BW) in Newton's.

2.5. Statistical analysis

Means, standard deviations (SD), 95% confidence intervals, and Cohen's D (*d*) effect sizes were calculated for all dependent measures. Effect sizes were computed as the absolute difference in means divided by the pooled SD and evaluated as small ($d < 0.40$), moderate ($d = 0.40–0.80$), and large ($d > 0.80$) (Cohen, 1992). Net ankle moments and GRFs were compared between unanticipated and anticipated landing conditions during the first 150 ms post-landing using a one-dimensional statistical parametric mapping (SPM) analysis in MATLAB (The Math Works, Inc., Natick, MA, USA) (Pataky, 2010). Discrete ankle joint and impact kinetics were compared between unanticipated and anticipated landing conditions using dependent samples *t*-tests. Statistical significance was considered for all analyses when $p \leq 0.05$.

3. Results

Time-averaged and 95% confidence intervals for net ankle moments during the unanticipated and anticipated landings are displayed in Fig. 3A–C. Results revealed a significantly greater plantar flexion moment during the unanticipated landing from 58 to 83 ms post-landing (Fig. 3A; $p = 0.004$; mean difference = 0.346 ± 0.005 Nm/kg; $d = 0.64–0.77$). Additionally, significantly greater inversion moment from 89 to 91 ms post-landing (Fig. 3B; $p = 0.050$; mean difference = 0.222 ± 0.002 Nm/kg; $d = 0.58–0.60$) during the unanticipated landing condition was observed in comparison to the anticipated landing condition. No significant differences were observed for internal rotation moment between the two landing conditions (Fig. 3C; $p > 0.05$).

Time-averaged and 95% confidence intervals for the vertical, medial, and posterior components of the GRF during the unanticipated and anticipated landing conditions are displayed in Fig. 4A–C. Significantly greater medial GRF during the unanticipated landing was found from 62 to 97 ms post-landing (Fig. 4B; $p < 0.001$; mean difference = 0.241 ± 0.020 BW; $d = 1.00–2.39$) compared to the anticipated landing condition. There were no significant differences between landing conditions for the vertical or posterior components of the GRF during the 150 ms post-landing ($p > 0.05$).

Peak ankle moments and impact kinetic data from the unanticipated and anticipated landing conditions are displayed in Table 1. Significantly greater peak plantar flexion moment ($p < 0.001$; $d = 1.10$) and peak inversion moment ($p = 0.006$; $d = 0.94$) were observed during the unanticipated landing condition when compared to the anticipated landing condition. The unanticipated landing condition also resulted in a significantly greater peak medial GRF ($p = 0.005$; $d = 1.14$), average ($p = 0.042$; $d = 0.66$) and peak medial loading rate ($p = 0.002$; $d = 1.03$) compared to the anticipated landing condition. No other significant differences found for any of the other impact kinetic parameters reported.

4. Discussion

While prior investigations provide insight to the kinematic (Simpson et al., 2018) and neuromuscular control (Dicus & Seegmiller, 2012; Gehring et al., 2014; Simpson et al., 2019) alterations during anticipated inversion perturbations, this investigation was novel in that we examined ankle joint and impact kinetics during unanticipated and anticipated inversion perturbations during a single-leg drop landing onto a laterally inclined platform. Results from this investigation indicate that significant alterations to ankle joint and impact kinetics occurred when inversion perturbations were anticipated. Most notably, significant reductions in ankle plantar flexion and inversion moment, medial GRF magnitude and loading rates were found during the anticipated landing condition. As a result, we were able to confirm our initial hypothesis that ankle joint and impact kinetics would be significantly increased during the unanticipated landing condition. To the author's knowledge, this was the first investigation that assessed ankle joint and impact kinetic parameters during unanticipated and anticipated inversion perturbations using a single-leg drop landing onto a laterally inclined platform.

During the unanticipated landing condition, significantly greater ankle plantar flexion moment was found in comparison to the anticipated landing condition (Table 1; Fig. 3A). Jump-landings require preparatory ankle plantar flexion, and in many instances, inversion to effectively attenuate impact forces during initial ground contact (Dicus & Seegmiller, 2012; Simpson et al., 2018). Talocrural plantar flexion and subtalar inversion during open kinetic chain movements increases the strain placed on the lateral ankle ligaments, mostly the anterior talofibular and calcaneofibular ligaments (Hertel, 2002). This reduces the ability of the intact ligaments to provide static joint stability while increasing the susceptibility to reach or exceed the maximum load to failure when rotational forces are imposed to the ankle joint complex during unanticipated ground contact (Li, Ko, Zhang, Brown, & Simpson, 2018; Terada & Gribble, 2015). Several case reports have shown that greater plantar flexion angle (Kristianslund et al., 2011; Terada & Gribble, 2015), and more recently plantar flexion moment (Gehring et al., 2014; Li et al., 2018), during initial ground contact are causative factors of a lateral ankle sprain injury. The increased plantar flexion moment during the unanticipated landing condition could be attributed to less sagittal plane ankle joint stiffness resulting in rapid sagittal plane displacement during landing. Previous studies suggest knowledge of an inversion perturbation elicits an altered feedforward motor control strategy to increase muscular co-contraction of the ankle dorsiflexors and plantar flexors (Gehring et al., 2014; Gutierrez et al., 2012; Simpson et al., 2019). Perhaps increased sagittal plane ankle joint stiffness was employed by our participants as a more effective preparatory landing strategy to attenuate impact forces and control sagittal plane joint displacement to reduce the plantar flexion moment during the anticipated inversion perturbation.

Similarly, significantly greater inversion moment during from 89 to 91 ms post-landing and peak inversion moment during the unanticipated landing condition was also found (Table 1; Fig. 3B). Greater inversion and/or internal rotation angle during initial foot contact when landing from a jump increases the moment arm of the subtalar joint (Fuller, 1999), which can augment the supination

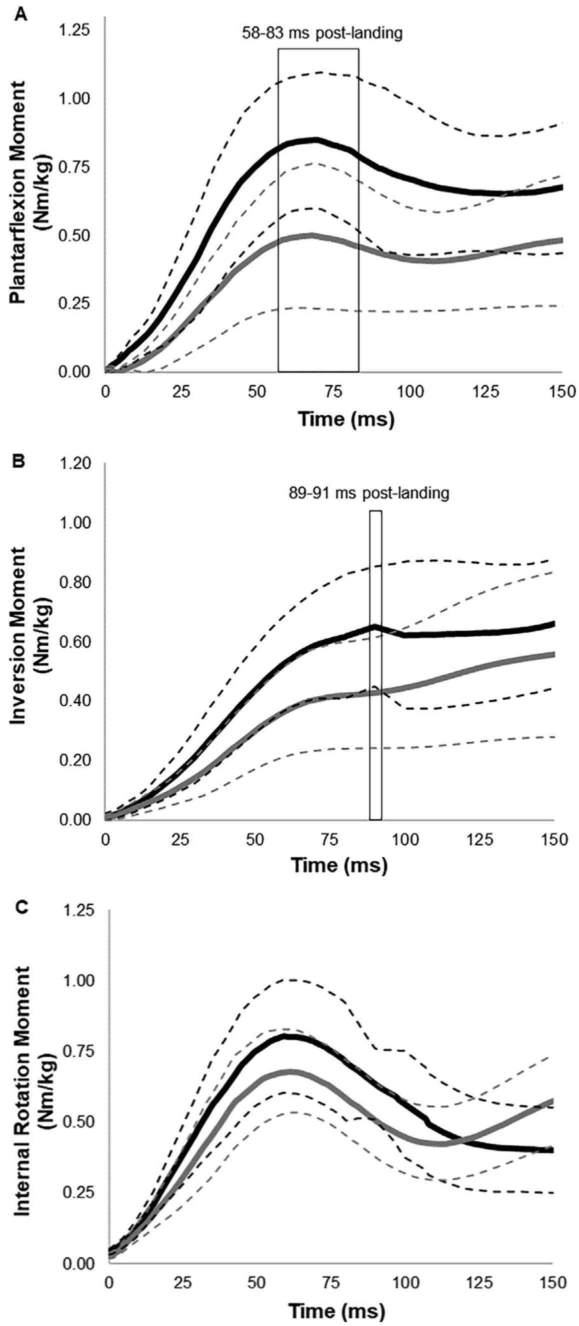

Fig. 3. Normalized sagittal (A), frontal (B), and transverse (C) plane ankle moment 150 ms post-landing during the unanticipated (solid black line) and anticipated (solid gray line) landing conditions. The black and gray dashed lines indicate the 95% confidence intervals for the unanticipated and anticipated landing conditions, respectively. Boxed area indicates statistical significance ($p \leq 0.05$).

moment of the ankle joint complex (Koshino et al., 2017). Indeed, increased inversion moments could possibly be explained by tri-planar supination of the ankle, or greater joint displacements isolated more in the frontal or transverse planes, during the unanticipated landing condition. Prior investigations examining anticipatory responses to inversion perturbations have reported reductions in ankle inversion angle at initial contact (Gehring et al., 2014), inversion displacement and inversion velocity (Dicus & Seegmiller, 2012; Simpson et al., 2018), in addition to increased preparatory and reactive fibularis longus amplitude and frontal plane muscular co-contraction (Gutierrez et al., 2012; Simpson et al., 2019). Furthermore, a recent investigation examining pre- to post-landing lower extremity kinematics reported increased preparatory hip flexion and hip adduction in anticipation to an inversion perturbation during a single-leg drop landing (Simpson et al., 2018). These aforementioned movement dynamics provide a plausible explanation for the significant reduction in inversion moments at the ankle during the anticipated landing condition. Given the

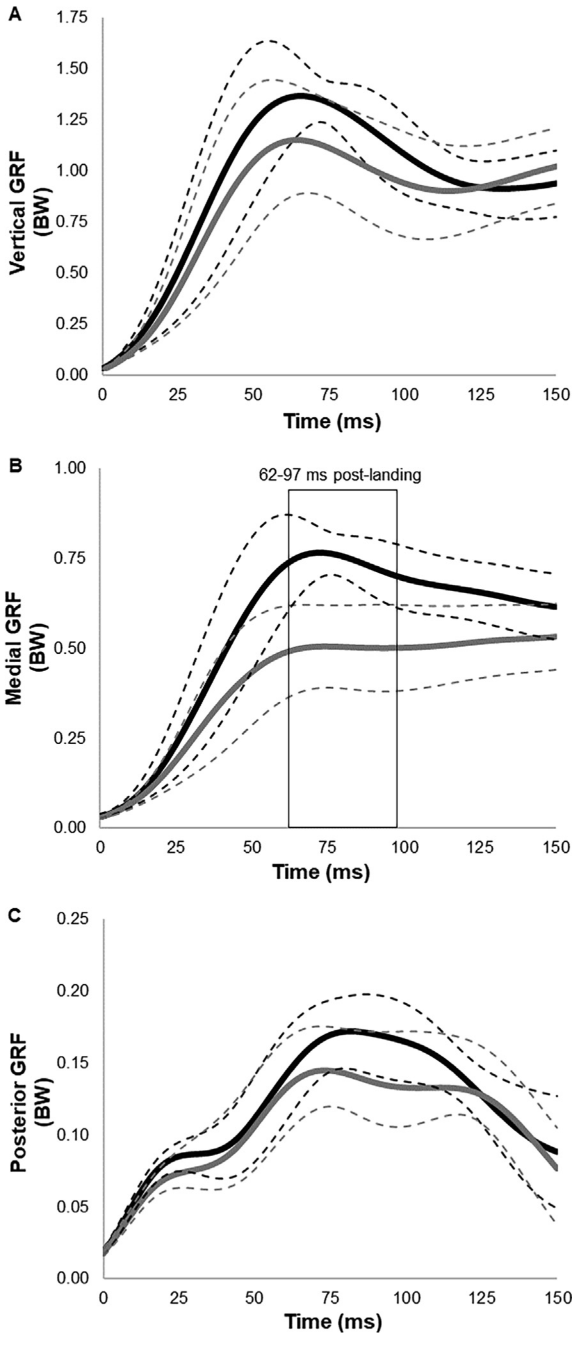

Fig. 4. Normalized vertical (A), medial (B), and posterior (C) components of the ground reaction force 150 ms post-landing during the unanticipated (solid black line) and anticipated (solid gray line) landing conditions. The black and gray dashed lines indicate the 95% confidence intervals for the unanticipated and anticipated landing conditions, respectively. Boxed area indicates statistical significance ($p \leq 0.05$).

available evidence (Dicus & Seegmiller, 2012; Gutierrez et al., 2012; Simpson et al., 2018, 2019), the cognitive awareness of a potentially injurious perturbation during landing appears to elicit a protective feedforward motor control strategy in attempt to increase frontal plane ankle joint stabilization to avoid excessive inversion moments that could cause damage to the lateral ankle ligaments.

In addition to changes in ankle moment, the unanticipated landing condition produced significantly greater medial GRF from 62 to 97 ms post-landing (Fig. 4B), peak medial GRF, average and peak medial loading rates when compared to the anticipated landing condition (Table 1). Dicus and Seegmiller (2012) reported peak fibularis longus activation occurred prior to peak vertical GRF, in addition to significant reductions in peak vertical GRF, during anticipated inversion perturbations. Furthermore, a recent

Table 1
Peak ankle moments and impact kinetics during the unanticipated and anticipated landing conditions (mean ± SD).

Variable	Unanticipated	Anticipated	t	p Value	Cohen's D	95% Confidence Interval of the Difference	
						Lower	Upper
Peak Plantar Flexion Moment (Nm/kg)	1.123 ± 0.456†	0.606 ± 0.524	4.416	< 0.001	1.100	0.262	0.773
Peak Inversion Moment (Nm/kg)	0.868 ± 0.206†	0.561 ± 0.451	3.254	0.007	0.935	0.102	0.513
Peak Internal Rotation Moment (Nm/kg)	1.083 ± 0.637	0.916 ± 0.596	1.734	0.108	0.271	−0.043	0.377
Peak Vertical GRF (BW)	1.753 ± 0.443	1.510 ± 0.557	1.668	0.121	0.487	−0.075	0.562
Average Vertical Loading Rate (BW/s)	27.216 ± 15.080	24.114 ± 14.057	0.809	0.434	0.213	−5.248	11.451
Peak Vertical Loading Rate (BW/s)	48.132 ± 25.054	43.362 ± 24.631	0.655	0.525	0.192	−11.109	20.650
Time to Peak Vertical GRF (ms)	70.231 ± 16.873	73.154 ± 23.075	−0.540	0.599	0.146	−14.724	8.879
Peak Medial GRF (BW)	0.903 ± 0.201†	0.667 ± 0.215	3.483	0.005	1.14	0.088	0.384
Average Medial Loading Rate (BW/s)	13.452 ± 6.225†	9.614 ± 5.406	2.278	0.042	0.660	0.167	7.510
Peak Medial Loading Rate (BW/s)	24.756 ± 10.626†	15.512 ± 7.271	4.050	0.002	1.033	4.270	14.218
Time to Peak Medial GRF (ms)	74.154 ± 19.321	76.077 ± 23.049	−0.314	0.759	0.091	−15.260	11.414
Peak Posterior GRF (BW)	0.231 ± 0.072	0.244 ± 0.105	0.447	0.663	0.149	−0.077	0.051
Average Posterior Loading Rate (BW/s)	2.850 ± 1.258	2.299 ± 2.023	−0.272	0.790	0.085	−1.341	1.043
Peak Posterior Loading Rate (BW/s)	6.445 ± 3.056	6.479 ± 3.691	−0.028	0.978	0.010	−2.714	2.646
Time to Peak Posterior GRF (ms)	81.077 ± 17.576	93.231 ± 26.923	−1.280	0.225	0.546	−32.843	8.535

† Indicates significantly greater than anticipated landing condition ($p \leq 0.05$).

investigation also observed increased fontal plane muscular co-contraction during anticipated inversion perturbations (Simpson et al., 2019), suggesting that a more advantageous feedforward and feedback neuromuscular control strategy is used during anticipated landings on a laterally inclined platform. Although we did not observe vertical impact kinetics to be significantly different between landing conditions in this study, the differences in results might be attributed to the differences in experimental protocols used across studies to produce an inversion perturbation upon landing. However, we did observe that when participants anticipated the inversion perturbation significant reductions in time-averaged medial GRF, peak medial GRF, peak and average loading rates. It is possible that increased preparatory activation of the lateral ankle musculature (Dicus & Seegmiller, 2012; Gutierrez et al., 2012), increased frontal plane muscular co-contraction (Simpson et al., 2019), reduced frontal plane ankle displacement (Gehring et al., 2014), and increased preparatory hip flexion (Simpson et al., 2018) previously demonstrated during anticipated inversion perturbations likely emerges as a protective landing strategy to attenuate medial loading on the ankle joint complex when landing on a laterally inclined surface.

Our results contribute to the limited, but growing body of literature that identifies the changes to lower extremity movement dynamics during anticipated inversion perturbations (Dicus & Seegmiller, 2012; Gehring et al., 2013; Simpson et al., 2018). It appears that a protective landing strategy emerges to reduce ankle joint loading when there is the potential of an injurious perturbation, and consequently, poses a major limitation for examining natural landing patterns during injury simulations to determine lateral ankle sprain injury risk. Although these studies identify changes to landing strategies in healthy individuals, these findings could have clinical implications for future studies in populations with chronic ankle instability that exhibit maladaptive movement adaptations in which a proximal to distal movement strategy is used in attempt to avoid the ankle from giving way out of increased fear of recurrent injury. Therefore, researchers and practitioners examining lateral ankle sprain injury mechanics and factors that contribute to recurrent injury are encouraged to implement experimental protocols that mitigate anticipatory responses to more accurately approximate the rapid and unanticipated mechanism of a lateral ankle sprain. The protocol used in the this study, which has been shown to mimic ankle kinematic patterns closely to those reported in real-time injuries (Simpson et al., 2018), is a novel protocol that separates unanticipated and anticipated inversion perturbations during landing, a common sport specific injury situation that initiates the mechanism of a lateral ankle sprain. While it may be difficult to completely remove anticipatory responses when using injury simulations, this protocol provides a means of mitigating anticipatory responses to analyze natural landing patterns to obtain biomechanical that can be extrapolated to real-time injury scenarios.

The main delimitation to the present study was that only participants with no self-reported history of a lateral ankle sprain injury were tested. Therefore, our findings are only representative of a healthy population and cannot be inferred to individuals with a lateral ankle sprain history, or chronic ankle instability. Secondly, only a total of two landings were analyzed for each participant used in this study (i.e. 30 total landings). Although we implemented this design to preserve the nature of the unanticipated mechanism of a lateral ankle sprain injury, this leads way to a greater chance of a type 2 statistical error, and therefore, our results should be interpreted with a mild degree of caution. Finally, proximal segment joint kinetics were not analyzed in this investigation. Examining proximal segment joint kinetic alterations, with and without the knowledge of an inversion perturbations, during single-leg drop landings is warranted to provide a more complete spectrum of the compensatory lower extremity movement dynamics that may occur in anticipation to injurious perturbations.

5. Conclusion

Our findings from this study suggest that knowledge of an inversion perturbation during a single-leg drop landing results in significant changes to ankle joint and impact kinetics. Anticipatory responses can confound data and prohibit an accurate assessment of underlying factors that contribute to an increased risk of a lateral ankle sprain. Therefore, clinicians and practitioners conducting injury risk assessments using drop landings onto an inverted surface should consider implementing protocols that control for anticipatory responses to more closely approximate the mechanisms of a lateral ankle sprain injury. However, additional research is warranted to determine the neuromuscular control strategies that occur during unanticipated and anticipated inversion perturbations to further substantiate the clinical implications our findings.

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