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Lecture

Military personnel with self-reported ankle injuries do not demonstrate deficits in dynamic postural stability or landing kinematics

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ABSTRACT

Background: The odds of sustaining non-contact musculoskeletal injuries are higher in Special Operations Forces operators than in infantry soldiers. The ankle is one of the most commonly injured joints, and once injured can put individuals at risk for reinjury. The purpose of this study was to determine if any differences in postural stability and landing kinematics exist between operators with a self-reported ankle injury in the past one year and uninjured controls.
Methods: A total of 55 Special Operations Forces operators were included in this analysis. Comparisons were made between operators with a self-reported ankle injury within one-year of their test date ($n = 11$) and healthy matched controls ($n = 44$). Comparisons were also made between injured and uninjured limbs within the injured group. Dynamic postural stability and landing kinematics at the ankle, knee, and hip were assessed during a single-leg jump-landing task. Comparisons were made between groups with independent *t*-tests and within the injured group between limbs using paired *t*-tests.
Findings: There were no significant differences in dynamic postural stability index or landing kinematics between the injured and uninjured groups. Anterior-posterior stability index was significantly higher on the uninjured limb compared to the injured limb within the injured group ($P = 0.02$).
Interpretation: Single ankle injuries sustained by operators may not lead to deficits in dynamic postural stability. Dynamic postural stability index and landing kinematics within one year after injury were either not affected by the injuries reported, or injured operators were trained back to baseline measures through rehabilitation and daily activity.

1. Introduction

Musculoskeletal injury is a significant health concern for the United States military resulting in lost duty time, disability, hospitalization, high healthcare costs, and ultimately impacts military readiness (Jones et al., 2000; Lauder et al., 2000). The odds of sustaining a traumatic injury (tear or rupture) to the shoulders, knees, or legs are six times greater in Special Operations Forces (SOF) operators than in infantry soldiers (Reynolds et al., 2009). Over 75% of non-contact musculoskeletal injuries reported by SOF operators are related to physical training and sports (Abt et al., 2014; Reynolds et al., 2009). The majority of injuries occur in the lower extremity with the ankle joint being one of the most commonly injured joints among Navy SOF operators (Kaufman et al., 2000) and airborne soldiers (Kragh et al., 1996; Lillywhite, 1991; Sell et al., 2010). In an isolated, acute ankle sprain, individuals are often able to return to activity quickly (Medina McKeon et al., 2014). However, residual sensorimotor (Gribble et al., 2016; Hertel, 2008), postural stability (Doherty et al., 2015a; Doherty et al., 2016a; Goldie et al., 1994; Wikstrom et al., 2010), and functional movement (Doherty et al., 2015c; Doherty et al., 2016c) deficits may persist up to one year following acute injury. Individuals have an increased risk of reinjury during the first year after an ankle sprain and may go on to develop chronic ankle instability (CAI) (Bahr and Bahr, 1997; Doherty et al., 2016b). It is important to understand the residual effect of a single self-reported ankle sprain on dynamic postural stability and landing patterns to refocus rehabilitation efforts for mitigation of recurrent

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injury.

Postural stability is defined as the ability to sustain the body in equilibrium by maintaining the projected center of mass within the limits of the base of support (Shumway-Cook and Woollacott, 2001). It is a dynamic process that requires afferent detection of body motion, integration of sensorimotor information within the central nervous system, and execution of an appropriate response in order to maintain the body in equilibrium (Riemann and Lephart, 2002a; Riemann and Lephart, 2002b). Acute ankle sprains have been associated with postural stability deficits during a single-leg stance and Star Excursion Balance Test (Doherty et al., 2015a; Doherty et al., 2016a; Goldie et al., 1994; Wikstrom et al., 2010). A single-leg jump landing task has been shown to identify dynamic postural stability deficits in individuals with CAI (Brown et al., 2010; Brown et al., 2015; Wikstrom et al., 2007; Wikstrom et al., 2012). However, the effects of a single self-reported ankle sprain on dynamic postural stability measures during a single-leg jump landing task are unknown. Dynamic measures of postural stability are preferred for military and athletic groups as they are more challenging than static tasks and may better differentiate between risk factors in healthy, physically active individuals (Sell et al., 2012).

Landing mechanics play an important role in force attenuation during jump landing tasks (Doherty et al., 2015c). Positioning of the hip, knee, and ankle during the landing phase contributes to the body's ability to absorb impact forces and recover stability during dynamic tasks (Devita and Skelly, 1992; Doherty et al., 2015c). Following first time acute lateral ankle sprain, individuals display increased hip flexion and ankle inversion on the injured limb (Doherty et al., 2015b; Doherty et al., 2015c). Though there is limited research on landing strategies following acute lateral ankle sprain, Doherty et al. suggest the changes observed are similar to movement patterns exhibited by individuals with CAI (Doherty et al., 2016c). Unilateral injury has been shown to affect bilateral performance (Doherty et al., 2015b; Doherty et al., 2016c), and Hass et al. suggest this may be due to central changes and may increase risk of future injury (Hass et al., 2010). While few studies have observed landing kinematics during a dynamic postural stability landing task (Delahunt et al., 2006), a change in landing strategy associated with a deficit in dynamic postural stability may offer insight regarding which functional movement patterns to address during rehabilitation to improve stability.

The effect of a single self-reported ankle injury on dynamic postural stability and landing mechanics during a dynamic postural stability task is unknown in a military population. While most single sprain incidents are perceived to minimally impact function, there is evidence suggesting these incidents might be significant enough to alter landing kinematics and dynamic postural stability (Doherty et al., 2015a; Doherty et al., 2015c). The purpose of this study was to determine if SOF operators with a previous ankle injury display differences in dynamic postural stability and landing mechanics compared to uninjured controls. We also compared these factors between the injured and uninjured limbs of those SOF operators with a self-reported ankle injury. We hypothesized that SOF operators that reported a previous ankle injury would have deficits in dynamic postural stability on their injured limb compared to their uninjured limb and compared to the control group. We also hypothesized that SOF operators with previous ankle injury would demonstrate increased hip flexion and knee extension on their injured limb at initial contact compared to their uninjured limb and compared to the control group which may expose them to a greater risk of reinjury (Gehring et al., 2013; Terada and Gribble, 2015). The results of this study may offer support for supplementing current rehabilitation and physical training with balance training for SOF operators who report ankle injury to reduce the risk for future lower extremity injury.

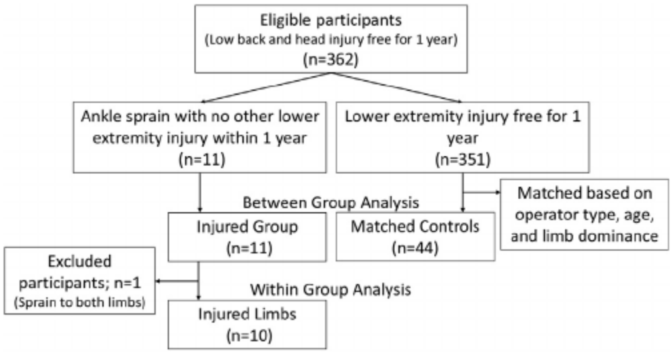

Fig. 1. Flow chart of eligible participants based on self-reported history and matched controls.

2. Methods

2.1. Participants

SOF operators from Air Force Special Operations Command (AFSOC), United States Army Special Operations Command (USASOC), and Naval Special Warfare (NSW) candidates were recruited and tested at Warrior Human Performance Research Laboratories, onsite research laboratories operated by personnel from the University of Pittsburgh. The University of Pittsburgh's Department of Sports Medicine and Nutrition has an ongoing research collaboration with multiple SOF groups designed to reduce the risk of injury and enhance performance of SOF operators. Several factors are considered as part of this effort including retrospective and prospective injury data, biomechanical, neuromuscular, physiological, and nutritional data. This study reports on a small subset of the data collected.

All operators and candidates enrolled in the ongoing research collaboration had been cleared for full duty and were free of self-reported musculoskeletal injury in the previous 3 months. A subset of 362 operators and candidates were included in this study and reported no low back or head injuries within one year prior to test date (Fig. 1). Eleven of the 362 enrolled had a self-reported history of ankle injury within one year prior to their test date and reported no additional lower extremity injuries within that one year period. The rest of the participants reported no lower extremity injuries within one year prior to test date and were included in the initial pool of potential participants to serve as the control group. The control group was narrowed by randomly selecting matched controls at the group level in a 1:4 ratio of injured to control limbs (Hennessy et al., 1999). Demographics for control and injured groups are listed in Table 1. Limbs were matched based on operator type (i.e., AFSOC, USASOC, NSW), age, and limb dominance. Participants were matched for age based on the following groupings: 20–28 years 29–36 years, i.e., for a give injured participant, matched controls would have to fall within the same age grouping. Limb dominance was determined by asking the participant which leg they would prefer to use to kick a ball (Lephart et al., 2002). For the side-to-side comparison, one participant was excluded due to injury to both ankles within one year prior to test date. All participants gave written consent approved by the University of Pittsburgh Institutional Review Board.

Table 1
Subject demographics.

	Injured (n = 11) Mean (SD)	Uninjured matched controls (n = 44) Mean (SD)	P value
Age (yrs)	27.5 (5.2)	26.1 (4.3)	0.48
Height (cm)	176.2 (8.9)	178.8 (7.3)	0.35
Mass (kg)	85.5 (11.8)	84.9 (9.6)	0.80

2.2. Instrumentation

Kinematic data were collected with at least 6 high-speed cameras (Vicon, Centennial, Colorado, USA) and ground reaction force data were collected with one force plate (Kistler Corp, Amherst, New York, USA) with sample frequencies of 200[16] and 1200[44] Hz, respectively. Data were synchronized using Vicon Nexus Software. This was a multisite study and quality control measures were taken to ensure standardized protocol (Gorton et al., 2009).

2.3. Procedures

2.3.1. Injury survey

Participants completed a verbal survey dictating any previous self-reported injuries. The injury data were recorded by a clinician in the University of Pittsburgh's Military Epidemiology Database (UPITT-MED) (Sell et al., 2010). Participants were required to answer questions regarding all injuries within one year prior to the test date. Variables related to the injuries included anatomical location, anatomical sub-location, cause of injury, activity when injury occurred, and injury type. Injury was defined as an injury to the musculoskeletal system (bones, ligaments, muscles, tendons, etc.) that resulted in alteration in tactical activities, tactical training, or physical training for a minimum of one day (Dick et al., 2007). If the injury occurred prior to enlistment, then the injury resulted in alteration in activities of daily living, training, or athletic activities for a minimum of one day. Self-reported ankle injuries were included if injury to one or more of the ankle ligaments resulted in the altered activities described above.

2.3.2. Dynamic postural stability and landing kinematics assessment

Sixteen reflective markers were placed on the participant's anatomical landmarks according the Vicon Plug-in-Gait (PIG) model modified for the lower extremity. A static capture was collected for each participant while standing in an anatomical neutral position and used as the baseline for joint angle calculations. Dynamic postural stability was assessed during a single-leg landing that has been shown to be reliable (Sell et al., 2012). The jump was initiated from two feet from a distance of 40% of the participants' height from the force plate. Participants were asked to jump over a 30 cm hurdle and land on the force plate with their test leg (single-leg). Participants were asked to place their hands on their hips and look straight ahead once their balance was recovered. This position was held for approximately 5 to 8 s after landing. Participants were given a minimum of three practice trials. Trials were discarded if the participant's non-test leg touched the test leg or the ground. Both kinematic and kinetic data were collected during the task.

2.4. Data reduction

Vicon Nexus Software was used to reconstruct 3D trajectories of the reflective markers and synchronized with the ground reaction force data. The marker trajectories were smoothed using a general cross-validation Woltring filter (Woltring, 1995). Ground reaction force data were filtered with a zero-lag, fourth-order low-pass Butterworth filter with a 20-Hz cutoff frequency using a custom MATLAB (v7.0.4, MATLAB, Natick, Massachusetts, USA) script. Ankle, knee, and hip joint angles were calculated from the YXZ Euler angles according to ISB guidelines, with inversion/eversion about the X, axis; flexion/extension about the Y axis, and internal/external rotation about the Z axis (Davis et al., 1991; Kadaba et al., 1990). Initial contact of the test foot during landing was defined as the first sample of the vertical ground reaction force to exceed 5% of the participant's body weight. This sample number was used to identify ankle dorsiflexion/plantar flexion, knee flexion, knee valgus/varus, hip flexion, and hip abduction/adduction angles at initial contact. Each variable was averaged over three trials. Ground reaction forces during the first 3 s following initial contact were used to calculated stability indices representing dynamic postural control (Sell et al., 2012). Stability indices in the anterior-posterior (APSI), medial-lateral (MLSI), and vertical (VSI) directions were calculated as mean square deviations about a zero point (Wikstrom et al., 2005). Dynamic Postural Stability Index (DPSI) is a composite of APSI, MLSI, and VSI.

2.5. Statistical analysis

Statistical analyses were performed using SPSS software (v22; SPSS; Chicago, Illinois, USA). The normality of the data was assessed using a Shapiro-Wilk test. Side-to-side comparisons within each group were assessed using a paired *t*-test when data were normally distributed or a Wilcoxon signed-rank test when not normally distributed. The paired *t*-tests and Wilcoxon signed-rank tests were in agreement for all comparisons, thus only the *P* values from the paired *t*-tests were reported. Between-group comparisons were assessed using an independent *t*-test when data was normally distributed or a Mann-Whitney *U* test when not normally distributed. The independent *t*-tests and Mann-Whitney *U* tests were in agreement for all comparisons, thus only the *P* values from the independent *t*-tests were reported. An alpha level of 0.05 was set a priori to determine statistical significance. Post hoc powers and effect sizes were calculated using G*Power software (v3.1.8) (Faul et al., 2007). Reported effect sizes for the within group analysis were calculated from the means and standard deviations of the differences, while effect sizes for the between group analysis were calculated from group parameters. Effect sizes were classified as small < 0.20, medium = 0.21–0.79, large > 0.80 (Cohen, 1988).

3. Results

Age, height, and mass were not found to be statistically significant between groups. Individuals with a single self-reported ankle injury reported the injury occurring on average 6.8 (SD 2.3) months prior to test date. The time between injury and test date ranged from 3.4–10.2 months. Fifty four percent ($n = 6$) of the self-reported ankle injuries occurred during physical training activities. The remaining injuries occurred due to tactical training ($n = 2$; 18%), recreational activity ($n = 2$; 18%), or were not reported ($n = 1$; 9%).

The means and standard deviations for dynamic postural stability and kinematics at initial contact for the side-to-side comparisons within the injured population are presented in Table 2. Injured participants had significantly lower APSI when performing the jump-landing protocol on their injured limb (mean 0.130 (SD 0.013)) compared to their uninjured limb (mean 0.135 (SD 0.015)), indicating worse stability in the anterior-posterior direction on the uninjured side. There were no significant differences in measures between injured and uninjured limbs when the injured limb was the dominant limb or when the injured limb was the non-dominant limb.

The means and standard deviations for dynamic postural stability and kinematics at initial contact for the analysis between injured and healthy limbs, including *P* values, are presented in Table 3. There were no significant differences found for dynamic postural stability measures or biomechanical measures when comparing injured limbs to healthy matched control limbs.

4. Discussion

Ankle injuries are one of the most common injuries among SOF operators. Injury to the ankle is known to compromise the integrity of the joint which predisposes the joint to reinjury. The purpose of this study was to examine dynamic postural stability measures and landing kinematics in SOF operators with a previous self-reported ankle injury and SOF operators without. The results show no significant differences in dynamic postural stability or landing kinematics between the injured and uninjured groups. Surprisingly, the injured SOF operators demon-

Table 2
Dynamic postural stability task performance and within injured group comparisons.

Injured participants (n = 10)	Injured side Mean (SD)	Uninjured side Mean (SD)	P value	Effect size d	Power (1-)
Balance measures					
MLSI	0.027 (0.005)	0.027 (0.004)	0.89	0.00	0.05
APSI	0.130 (0.013)	0.135 (0.015)	0.02	0.83	0.65
VSI	0.332 (0.051)	0.340 (0.056)	0.42	0.28	0.12
DPSI	0.358 (0.051)	0.365 (0.059)	0.35	0.33	0.16
Biomechanical Measures					
Hip flexion (+) at IC	27.1 (10.1)	26.1 (6.4)	0.59	0.20	0.09
Hip abduction ( ) at IC	10.7 (5.4)	9.5 (4.5)	0.63	0.19	0.08
Knee flexion (+) at IC	12.0 (5.3)	10.4 (5.4)	0.08	0.73	0.54
Knee valgus (+) at IC	3.7 (4.1)	3.8 (3.5)	0.99	0.01	0.05
Ankle plantar flexion ( ) at IC	22.7 (11.1)	28.0 (14.1)	0.37	0.34	0.16

Means and standard deviations (SD) of balance measures (ground reaction forces, N) and biomechanical measures (angles, °). *Statistically significant differences between injured and uninjured sides ($P < 0.05$).

Table 3
Dynamic postural stability task performance and comparisons between injured and healthy groups.

	Injured limbs Mean (SD)	Healthy limbs Mean (SD)	P value	Effect size d	Power (1-)
Balance measures					
MLSI	0.028 (0.006)	0.030 (0.006)	0.58	0.33	0.16
APSI	0.134 (0.005)	0.136 (0.014)	0.40	0.19	0.09
VSI	0.344 (0.044)	0.326 (0.039)	0.19	0.43	0.24
DPSI	0.371 (0.041)	0.354 (0.039)	0.21	0.42	0.24
Biomechanical measures					
Hip flexion (+) at IC	28.0 (10.2)	30.0 (7.5)	0.55	0.22	0.10
Hip abduction ( ) at IC	10.7 (5.4)	9.5 (4.8)	0.52	0.23	0.11
Knee flexion (+) at IC	12.5 (5.8)	12.9 (4.2)	0.86	0.08	0.06
Knee valgus (+) at IC	2.7 (4.3)	4.1 (3.6)	0.38	0.35	0.18
Ankle plantar flexion ( ) at IC	21.5 (10.6)	25.6 (9.6)	0.30	0.41	0.18

Means and standard deviations (SD) of balance measures (ground reaction forces, N) and biomechanical measures (angles, °). *Statistically significant differences between right and left sides ($P < 0.05$).

strated greater APSI on the uninjured limb compared to the injured limb suggesting that the SOF operators had better stability in the anterior-posterior direction on the injured limb. Our results differ from our initial hypotheses that past ankle injury would impair dynamic stability and compromise landing kinematics. This may suggest that postural stability of the injured SOF operators had either returned to baseline levels through physical training and regular daily activities, or their single injuries did not alter postural stability as measured by the DPSI.

Approximately 3% of our sample had self-reported a previous ankle injury within one year prior to test date. This is low compared to studies completed in similar populations (Almeida et al., 1999; Jones et al., 1993), but may be due to our one year limitation. Studies that have considered just injury within the past one year, report similar findings to ours (Lovalekar et al., 2016a; Lovalekar et al., 2016b). Although the number of injuries reported was low, the breakdown of activity when injury occurred is similar to that of previously reported data in similar military populations (Abt et al., 2014; Lovalekar et al., 2016a). We chose to limit injury history to one year as the relative risk of injury ranges from 9.8 to 3.8 for ankles injured in the previous 6–12 months compared to uninjured ankles (Bahr and Bahr, 1997). Ankle injuries are often thought to have long term effects leaving the injured ankle unstable. However, in the case of a single sprain, individuals do not show deficits in proprioception or strength (Willems et al., 2002), and we have shown that individuals do not display postural stability deficits or altered landing mechanics.

The observation that anterior-posterior stability was better on the injured limb compared to the uninjured limb was surprising, but may not be a meaningful difference. The observed effect size was large (0.83) and similar to effect sizes reported by Wikstrom et al. comparing dynamic postural stability in subjects with self-reported ankle injuries and healthy controls (Wikstrom et al., 2007). However, based on intraclass correlation coefficients (ICC) found by Wikstrom et al. (Wikstrom et al., 2005), we calculated the minimum difference (Weir, 2005) in APSI values for the difference to be considered real as 0.055. The observed difference between the APSI values, while statistically significant, only differed by 0.005. It is possible that the injured SOF operators had a stiffer landing on their injured limb leading to less anterior-posterior motion when stabilizing after landing resulting in a smaller APSI value. It is also possible that given the number of comparisons, one statistically significant finding may be due to chance. Doherty et al. demonstrate balance of both the involved and uninvolved limbs is impaired following acute ankle injury (Doherty et al., 2015a). Conversely, Perron et al. did find differences between injured and uninjured limbs following acute ankle injury, but question the clinical significance of this finding (Perron et al., 2007). Though we did not find bilateral differences, we also did not find differences between groups, which may suggest a single sprain does not have a large enough effect to cause central changes impacting postural stability.

This is the first study to use a single-leg jump landing task to quantify dynamic postural stability in individuals with a single self-reported ankle sprain. The dynamic postural stability means reported here are comparable to those previously reported on young, healthy individuals completing a similar jump landing task (Sell et al., 2012). However, our results conflict with other researchers who have identified postural stability deficits in individuals with acute lateral ankle sprain during static and quasi-static protocols (Doherty et al., 2015a; Goldie et al., 1994). We expected a more challenging, dynamic task would detect differences between the groups, but given the low number of self-reported injuries, our study was underpowered. Although the task utilized was arguably more challenging compared to a quasi-static task, it may not have been challenging enough to detect differences in the injured limbs (Liu et al., 2013). Time from injury on average was 6.8 months, which is outside of the acute injury period many studies have considered (1–6 months). (Doherty et al., 2015a; Goldie et al., 1994; Perron et al., 2007) While we showed no difference in DPSI scores due to self-reported injury, there may be other neuromuscular factors that were not examined that could have been affected.

There were no significant differences found between the positions of the hip, knee, or ankle at initial contact between the injured and uninjured groups as well as between the injured and uninjured limbs. Effect sizes ranged from 0.01–0.73 for the within group comparison and 0.08–0.41 for the between group comparison suggesting that any differences are not clinically relevant. This result may be due to participants using a variety of different landing strategies to regain stability after landing. While the ankle contributes to the deceleration moment and control of the center of mass when landing, control at the knee and hip also contributes to center of mass deceleration (Devita and Skelly, 1992; Doherty et al., 2015c). Lower extremity joint positioning at initial contact is often a point of interest in jump-landing maneuvers as knee and hip position at initial contact have been identified as mechanism for injury (Fong et al., 2009). However, time averaged differences may be more relevant as Doherty et al. (Doherty et al., 2015c), and Caulfield and Garrett (Caulfield and Garrett, 2002) showed that differences in time-averaged angular displacements at the ankle, knee, and hip exist both prior to and post landing in individuals with previous ankle injury during a drop-landing task. Time averaged angular displacements should be considered in future studies.

This study has several limitations. The sample size for the injured population was small. More injuries may have shown larger differences between groups. The severity of ankle injury and exact structure involved in each case was self-reported. While the self-reported data suggest these injuries were lateral ankle sprains, it cannot be ruled out that other tissues or structures were involved. Also, perceived instability was not collected in control and injured groups. While control participants had not sustained any lower extremity injuries within the one year prior to test date, it is possible that they had some residual effects from an injury occurring > one year prior. Information regarding SOF operator rehabilitation strategies after injury would have been useful in assessing efficacy of certain rehabilitation efforts. Future studies in SOF operators should determine ankle instability status and keep record of post injury rehabilitation efforts.

5. Conclusions

This study showed that dynamic postural stability measures and landing mechanics are not significantly altered in SOF operators that have suffered a single self-reported ankle injury within one year prior when compared to healthy SOF operators. Injured SOF operators demonstrated better stability in the anterior-posterior direction on their injured limb compared to their uninjured limb, but this is arguably not a meaningful difference. These results suggest current human performance training and rehabilitation may adequately restore postural stability or that the single self-reported injury did not alter postural stability or landing mechanics. It is also possible that following ankle injury dynamic postural stability is restored through daily activities the SOF operators complete.

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