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Movement adjustments in preparation for single-leg jumps in individuals with functional ankle instability

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ABSTRACT

There is some evidence showing that people with functional ankle instability (FAI) can present changes in postural control during the landing phase of a jump. These studies also show preliminary results indicating possible changes during phases prior to landing. Therefore, the objective of this study was to investigate whether movement adjustments prior to a jump are different between people with and without FAI. Sixty participants with (n = 30) and without (n = 30) FAI participated in this study. The main outcome measures were the variability of range of motion in ankle inversion/eversion and dorsiflexion/plantarflexion; and variability of center of pressure for the directions anterior-posterior and medio-lateral during the pre-jump period for drop jump, vertical jump and during single-leg stance. The group with instability showed more variability of center of pressure in anterior-posterior direction ($p = 0.04$) and variability of range of motion in ankle dorsiflexion/plantar flexion ($p = 0.04$) compared to control in the single-leg stance test. For the within-group comparisons, the group with instability showed more variability of center of pressure in anterior-posterior direction in the drop jump higher than single-leg stance and vertical jump. The same pattern was seen for the control group. Thus, this study suggests that people with FAI have greater ankle range of motion variability and center of pressure variability in the anterior-posterior axis when compared to healthy individuals during single-leg stance. For those same two variables, preparation for a drop jump causes more postural instability when compared to the preparation for a vertical jump and to single-leg stance.

1. Introduction

The ankle joint is subjected to constant stress during sports practice, and because of its anatomical design, it is highly prone to injury (Fong, Hong, Chan, Yung, & Chan, 2007; Gerber, Williams, Scoville, Arciero, & Taylor, 1998). Between 2002 and 2006, more than 3 million ankle sprains were reported in emergency departments throughout the USA (Waterman, Owens, Davey, Zacchilli, & Belmont, 2010). After-effects are a common concern following these sprains, with patients

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reporting sequelae that can last up to three years (Gerber et al., 1998; van Rijn et al., 2008). Due to these sequelae, there is often a decrease in physical activities and an increase in the risk of recurrent sprains, which can lead to chronic ankle instability (Hertel, 2002; Hubbard-Turner & Turner, 2015).

Although there are different theories on ankle instability, many researchers have investigated the role of functional deficits in people with chronic ankle instability, naming this particular condition functional ankle instability (FAI) (Hertel, 2002). It is important to identify the changes in function that are usually present after an ankle sprain as this can guide treatment and procedures intended to prevent new sprains (de Noronha, França, Haupenthal, & Nunes, 2013; Hiller, Refshauge, Herbert, & Kilbreath, 2008). Some of these possible changes related to FAI have been previously reported, particularly those related to sensorimotor control (McKeon & Hertel, 2008; Munn, Sullivan, & Schneiders, 2010).

A meta-analysis presented by Munn et al. (2010) showed evidence that sensorimotor control is impaired in people with FAI, particularly for the variables joint position sense and postural control. The studies on postural control used three different measurements: Star Excursion Balance Test, single-leg stance test, and time to recover balance in single-leg stance after a jump.

Studies often use the jump in their measurements (Brown, Ross, Mynark, & Guskiewicz, 2004; de Noronha, Refshauge, Crosbie, & Kilbreath, 2008; Ross & Guskiewicz, 2004, 2006; Ross, Guskiewicz, & Yu, 2005; Wikstrom, Tillman, & Borsa, 2005) because it is a complex activity, regularly seen in sports and highly related to ankle sprains. The results of these studies show that people with FAI can present changes during the landing phase of a jump (Brown et al., 2004; de Noronha, Refshauge, & Crosbie et al., 2008; Ross & Guskiewicz, 2004, 2006; Ross et al., 2005; Wikstrom et al., 2005), with preliminary results indicating possible changes during phases prior to landing (Delahunt, Monaghan, & Caulfield, 2006; de Noronha, Refshauge, & Crosbie et al., 2008).

de Noronha, Refshauge, and Crosbie et al. (2008) investigated the variability in inversion range of motion (ROM) during the preparation phase prior to a single-legged drop jump in people with FAI, showing that people with FAI had increased range of motion (ROM) of ankle inversion when compared with healthy controls. Such findings present the possibility that people with FAI will be affected while preparing for a challenging task. However, as single-leg stance tests have shown to be different in people with FAI, the question remains: are the changes presented by de Noronha, Refshauge, and Crosbie et al. (2008) due to a preparation for a jump or are those changes the same as those seen during the single-leg stance tests, as reported by Munn et al. (2010)? Therefore, the aim of this study was to investigate whether movement adjustments prior to a jump are different between those with and without FAI. In addition, we compared the movement adjustments happening prior to a jump to those happening during an one-legged stance test.

2. Methods

2.1. Design

This was a cross-sectional study investigation of whether there were differences in the variability for inversion/eversion (I/E) and dorsiflexion/plantar flexion (D/P) in two different conditions between people with and without FAI. We also compared the variability for the center of pressure (COP) in the anterior-posterior (AP) and medio-lateral (ML) directions immediately prior to a jump.

2.2. Participants

Sixty participants from the academic community of Santa Catarina State University, aged between 16 and 35 years, with and without FAI agreed to participate in the study. To be eligible for the FAI group, participants needed to have a history of at least two lateral ankle sprains in the same ankle, with the latest sprain between 12 and 2 months previous to study enrollment and a score of less than 23 in the *Cumberland Ankle Instability Tool – Português* (CAIT-P) (de Noronha, Refshauge, Kilbreath, & Figueiredo, 2008; Gribble et al., 2013). The FAI could be unilateral or bilateral. For the control group, participants could not have a history of ankle sprain and should have a score over 27 in the CAIT-P. Exclusion criteria for both groups were history of surgery and/or fracture in the lower limbs or any vestibular, neurological or musculoskeletal disease that could interfere with or was a contraindication to the procedures of the study. A lateral ankle sprain was defined as an inversion movement beyond the physiological joint limit followed by at least one of the following symptoms: persistent pain for more than one day, edema for more than one day, hematoma for more than one day, inability to participate in routine physical activity for more than one day (Fong, Chan, Mok, Yung, & Chan, 2009; Hiller et al., 2008). Participants from each group were paired according to age (range of 2 years), height (range of 3 cm), and mass (range of 3 kg) (Table 1). The study was approved by the Human Research Ethics Committee of Santa Catarina State University (registration number 03967912.6.0000.0118), and consent was granted by all participants.

2.3. Procedures

Initially a researcher, not involved in the data collection, verified the inclusion/exclusion criteria for the participants to define group allocation; ensuring the researchers involved in data collection were blinded to the CAIT-P score. Data

Table 1
Characteristics of participants.

	FAI group (n = 30)	Control group (n = 30)
Male	15	15
Female	15	15
Age (years)	22.7 ± 3.1	23.3 ± 2.9
Height (m)	1.7 ± 0.1	1.7 ± 0.1
Body mass (kg)	71.5 ± 12.6	70.4 ± 13.2
CAIT-P score (points)	16.5 ± 5.0	29.5 ± 0.8
History of ankle sprains[a] (n)	3.7 ± 2.3	0
Time from last ankle sprain (months)	5.3 ± 3.4	0

[a] Analyzed limb: FAI Group less score in CAIT-P and Control Group limb paired according to dominancy. FAI: Functional ankle instability; CAIT-P – *Cumberland Ankle Instability Tool – Português* questionnaire.

collection was performed for both limbs in all participants. Participants were instructed to avoid any physical activity at the testing days and to wear light sporting clothes and be barefoot during the tests.

2.4. Instruments

Procedures and assessments involved the measurement of ROM and stabilometry. For ROM, we used two MTx motion trackers (Xsens Motion Technologies, Enschede, The Netherlands) which are inertial sensors (accelerometers and gyroscopes) in combination with magnetic sensors (Ferrari et al., 2010; Saber-Sheikh, Bryant, Glazzard, Hamel, & Lee, 2010). Each tracker was placed on the skin with double-sided tape and Velcro tapes. One tracker was placed anterior medially on the shank, 10 cm above the medial malleolus, and the second tracker was placed on the dorsum of the foot, on the tarsometatarsal joint, parallel to the 5th metatarsal bone (Fig. 1). Before the beginning of each assessment, the participants remained in single-leg stance, holding the contralateral leg at approximately 90° of knee flexion and approximately 10° of hip flexion (natural and comfortable position), with external support to maintain balance. This was used to register the initial position with the motion trackers, for the three movement axes. Data was collected at 120 Hz using a second-order Butterworth low-pass filter with cutoff frequency of 15 Hz in Matlab (Mathworks, Natick, MA). Data related to I/E and D/P was recorded for analysis.

For stabilometry data, we used a force platform (Biomec 400, EMG System do Brasil Ltda., Brazil) to record vertical ground reaction force at 500 Hz with a second-order Butterworth low-pass filter with cutoff frequency of 35 Hz. We also collected data on COP for the AP and ML direction. Data from the force platform sensors were converted into COP data using the EMG System software and later analyzed in Matlab.

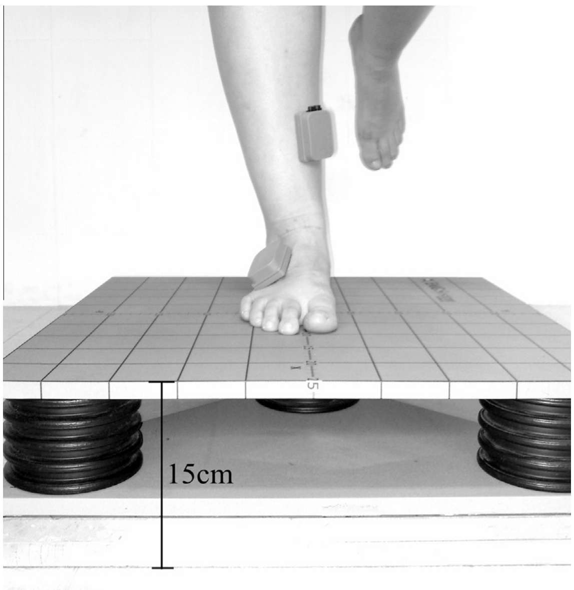

Fig. 1. Position of trackers and of force platform for the drop jump.

2.5. Assessment

Assessment was comprised of three tests. Participants were given the opportunity to practice all tests as many times as they felt necessary to be fully comfortable with the procedures. None of the participants required more than two practice tests. The orders of the three tests and the side to be tested were decided via randomization.

2.5.1. Drop jump

After initial position was recorded with the trackers, the participant was instructed to maintain single-leg stance on a force platform 15 cm above the ground (Fig. 1), without external support and with the hands on the waist. Data collection was initiated from the moment the participant informed the researcher that they found their balance. The participant then remained in this position for 7 s and was then instructed to jump forwards to a sign placed on the floor 30 cm from the edge of the force platform, landing on the same leg as the take-off foot. Participants performed five valid trials for each limb, with a minimum interval of 30 s between trials. A trial was discarded if the participant lost their balance during the pre-jump period, touched the ground with the contralateral foot or moved the hands away from the waist.

2.5.2. Vertical jump (hop variation)

The same calibration procedures were performed as described above. Data collection was initiated from the moment the participant informed the researcher that they found their balance. The participant then remained in this position for 7 s and was instructed to perform a counter-movement maximum vertical jump. The landing happened on the same leg of the jump. Data was collected from three valid trials for each limb, with a minimum interval of 30 s between trials. For all trials, the participants received a standard verbal stimulus to reach the highest possible jump. A trial was discarded when the participant lost balance during the pre-jump period, touched the ground with the contralateral foot or moved the hands away from the waist.

2.5.3. Single-leg stance

The same calibration procedures were performed as described above. The participant remained in single-leg stance for 15 s, and data was collected for three valid trials for each limb, with a minimum interval of 30 s between trials. A trial was discarded when the participant lost balance during the pre-jump period, touched the ground with the contralateral limb or moved the hands away from the waist. Single-leg stance data was collected to be used as control data of others tests.

2.6. Data analysis

To analyze the movement adjustments, we collected the following variables for each trial:

- Variability of ROM in ankle I/E and D/P during the pre-jump period for drop jump and vertical jump;
- Variability of COP for the directions AP and ML during the pre-jump period for drop jump and vertical jump;
- Variability of ROM for ankle I/E and D/P during the single-leg stance;
- Variability of COP for the directions AP and ML during the single-leg stance.

Variability of each trial was collected as the standard deviation (SD) of the ROM during each trial and the SD of the COP position of each trial (Knapp, Lee, Chinn, Saliba, & Hertel, 2011). For the analyses during the pre-jump period, we selected the data set between 1 and 4 s prior to take-off (Fig. 2). For the trackers, the peak of the acceleration was considered as the beginning of the take-off (Quagliarella, Sasanelli, Belgiovine, Moretti, & Moretti, 2010). For the analyses using the force

Fig. 2. Pre-jump period analyzed. t0 is the moment of take-off; the one-second interval between t0 and t1 was discarded before analysis; the three-second interval between t1 and t2 was the total period analyzed in the jumps.

platform, the moment of no contact between the participant and the force platform was considered as the beginning of the jump (vertical ground reaction force <10 N (Iida, Kanehisa, Inaba, & Nakazawa, 2012)).

For the single-leg stance, we discarded the first two seconds of each trial and used the following three seconds for analysis. All data were analyzed through computational routines developed with Matlab, and the mean of the SDs of each trial was used for the final analyses.

2.7. Statistical analysis

For those from the FAI group who had history of bilateral FAI, we used the ankle with the lowest CAIT-P. These were paired with the control group according to limb dominance, which was determined by asking the participant which limb they used to kick a ball.

Sample size calculation determined that 28 participants in each group provided 80% power and alpha of 5% when considering a mean difference of 0.6° and SD of 0.8° in variability of ROM in ankle I/E during the pre-jump period (de Noronha, Refshauge, & Crosbie et al., 2008). The investigator responsible for the data analysis and statistical analysis was blinded throughout the study.

Three 2-factor mixed model ANOVA were conducted to analyze the effect of ankle instability on drop jump, vertical jump, and single-leg stance and to verify the interaction between factors. Bonferroni post hoc test was used to analyze simple main effects for significant interactions. In addition, a post-hoc Pearson correlation analysis was conducted between the variability of ROM D/P and variability of COP AP during single-leg stance, using data from both groups. An alpha level of 5% was used for all statistical tests. SPSS version 17.0 software (SPSS Inc., Chicago, IL, USA) was used to analyze the data.

3. Results

For the between-group comparisons, we found more movement adjustment variability in the FAI group in the single-leg stance test for the COP AP ($p = 0.04$) and for ROM D/P ($p = 0.04$). There was no between-group difference for any of the other comparisons (Table 2).

For the within-group comparisons, the FAI group showed more movement adjustment variability in COP AP during the drop jump, which was higher than for single-leg stance [mean difference 0.15 cm (95% CI, 0.05–0.25)] and vertical jump [mean difference 0.15 cm (95% CI, 0.06–0.24)] (Table 2). The same pattern was seen for the control group, with more COP AP variability during the drop jump test when compared to the single-leg stance test [mean difference 0.14 cm (95% CI, 0.04–0.24)] and the vertical jump test [mean difference 0.09 cm (95% CI, 0.01–0.18)] (Table 2).

For the post-hoc analysis, there was a strong correlation ($r = 0.801$; $p = 0.001$) between the COP AP and ROM D/P in the FAI group. In the control group, the correlation between COP AP and ROM D/P was low ($r = 0.334$; $p = 0.07$).

4. Discussion

The study showed that during single-leg stance, people with FAI have more AP movement adjustments than healthy people; this was seen through the ROM D/P and COP AP analyses. We also found that movement adjustments in COP AP are

Table 2
Between- and within-group comparisons for the Drop Jump test, Vertical Jump test, and Single-Leg Stance test.

Group	Drop jump (mean ± SD)	Vertical jump (mean ± SD)	Single-leg stance (mean ± SD)	Univariate test
ROM I/E (°)				
FAI	0.47 ± 0.23	0.51 ± 0.29	0.44 ± 0.19	p = 0.240
Control	0.46 ± 0.27	0.47 ± 0.23	0.39 ± 0.19	p = 0.110
Mean difference (95% CI)	0.02 (−0.12 to 0.14)	0.05 (−0.08 to 0.18)	0.05 (−0.04 to 0.15)	
ROM D/P (°)				
FAI	0.48 ± 0.22	0.52 ± 0.38	0.50 ± 0.33	p = 0.657
Control	0.43 ± 0.30	0.44 ± 0.41	0.35 ± 0.18	p = 0.228
Mean difference (95% CI)	0.05 (−0.09 to 0.19)	0.08 (−0.12 to 0.29)	0.15 (0.01–0.28)*	
COP AP (cm)				
FAI	0.66 ± 0.32	0.51 ± 0.23	0.51 ± 0.26	p = 0.001†
Control	0.55 ± 0.20	0.45 ± 0.20	0.40 ± 0.13	p = 0.002[1]
Mean difference (95% CI)	0.11 (−0.03 to 0.25)	0.05 (−0.06 to 0.16)	0.11 (0.01–0.22)*	
COP ML (cm)				
FAI	0.44 ± 0.10	0.46 ± 0.12	0.45 ± 0.10	p = 0.815
Control	0.43 ± 0.08	0.46 ± 0.11	0.41 ± 0.09	p = 0.173
Mean difference (95% CI)	0.01 (−0.04 to 0.06)	0.01 (−0.07 to 0.06)	0.04 (−0.01 to 0.09)	

* Significant difference $P \leqslant 0.05$.
† Significant difference in FAI Group between Drop Jump × Single-Leg Stance, and Drop Jump × Vertical Jump.
[1] Significant difference in Control Group between Drop Jump × Single-Leg Stance, and Drop Jump × Vertical Jump.

greater pre-drop jump than pre-vertical jump and during single-leg stance for all participants. No differences between groups were found for the drop jump and vertical jump.

Therefore, our results contradict and complement the results from de Noronha, Refshauge, and Crosbie et al. (2008). Contrary to our results, de Noronha, Refshauge, and Crosbie et al. (2008) reported that people with FAI had more movement adjustments (variability) in ROM I/E prior to a drop jump; however, they only analyzed a time window of 1.5 s (0.75–2.25 s prior to the jump), while in the present study we analyzed a time window of 3 s (1–4 s prior to the jump). Therefore, the current analysis complements the analysis of de Noronha, Refshauge, and Crosbie et al. (2008) because we increased the analyzed time window.

The larger window of analysis might cover moments of large instability (close to takeoff) and also moments of more stability (close to equilibrium), therefore the increased time window could have dissipated possible differences that were only seen in smaller time windows, by decreasing the overall mean value. Nevertheless, we ran a preliminary analysis using small time windows, similar to that presented by de Noronha, Refshauge, and Crosbie et al. (2008) and we did not find any between-group differences for any of the outcomes analyzed. Therefore, it seems that what was seen in the study by de Noronha, Refshauge, and Crosbie et al. (2008) was not reproduced in the current study. The reason for the differences between the studies could lie in instrumentation because de Noronha, Refshauge, and Crosbie et al. (2008) used electromagnetic fields to gather data while we used inertial sensors with the same purpose. Yet another possibility is the presence of type II error; however the sample size was calculated taking into account the difference seen in the study by de Noronha, Refshauge, and Crosbie et al. (2008) aiming for a power of 80%.

In the present study, the only differences between the FAI group and the control group were detected during the single-leg stance test. The FAI group had more ROM D/P and COP AP variability than the control group. Similar differences have been previously reported (Tropp & Odenrick, 1988; Tropp, Odenrick, & Gillquist, 1985), particularly in a systematic review with a meta-analysis of 10 studies (Munn et al., 2010) in which most studies analyzed the area of the ellipse formed during the single-leg stance test.

In contrast with our results, the study by Knapp et al. (2011) that also investigated COP AP and ML separately, reported a larger variability in COP ML for the FAI group and no difference between groups for COP AP when single-leg stance was tested with the eyes closed. If we consider the literature, it seems that some studies point to an impairment in the frontal plane (de Noronha, Refshauge, & Crosbie et al., 2008; Hertel, 2002; Hiller, Kilbreath, & Refshauge, 2011; Munn et al., 2010) while others in the sagittal plane (Basnett et al., 2013; Hoch, Staton, Medina McKeon, Mattacola, & McKeon, 2012), leading to a conclusion that people with FAI can have impairment in ankle movement in any direction.

For the current study, the task of performing jumps was used as a way to take the focus of participants away from their motor performance and balance around the ankle, forcing them to focus on the task ahead. Interestingly, only when such distraction was not present (during the single-leg stance) we were able to see a difference in motor performance between groups. A possible explanation for the between group difference in single-leg stance and for the similarity between groups in movement adjustments during the preparation for the drop jump and vertical jump may be related to how participants concentrated on the task and likely the opposite of our initial thoughts. The fact that the participants were required to perform a balance task could have created the need in the participants to be well balanced so they could perform the task ahead (the jump). In contrast, considering that the single leg stance task was not followed by any other task, the participants could have unconsciously reached a level of sufficient stability for single leg stance, without any preparation for performance in any subsequent task. Therefore, if concentration really plays such role in balance in people with FAI, clinicians should take it into account when designing rehabilitation programs for patients with FAI.

Regarding the tests, we were able to verify that there is more COP AP variability prior to a drop jump than prior to a vertical jump and more than the single-leg stance. It is possible that the explanation for such difference is based on the characteristics of a drop jump, because it requires the body to be projected forward, possibly triggering an initial forward oscillation even before the actual jump. Additionally, knowing that drop jumps stimulates more postural instability than single-leg stance and vertical jumps can be an important piece of information for clinicians when including jumps in their treatment programs. Clinicians may be able to explore the different phases of a jump (preparation phase, landing phase, etc) to challenge more or less the postural control of patients.

After analyzing the current results, we ran a post hoc analysis investigating a possible correlation between the results for the variability of ROM D/P and COP AP during the single-leg stance, separately for each group. We found that there was only a strong correlation for the FAI group, which could be an indication that increased variability of ROM D/P creates an increased variability of COP AP, or vice versa. However that same strong correlation was not seen in the control group. Nevertheless we need to be cautious when analyzing these results, as we cannot be sure that one variable affects the other due to the nature of the correlation tested. Further investigation is warranted in this area.

5. Conclusion

The results from the present study show that people with FAI have greater ROM D/P variability and greater COP variability in the AP axis when compared to healthy individuals during single-leg stance. We also found that preparation for a drop jump causes more postural instability when compared to the preparation for a vertical jump and to single-leg stance.

Future studies could further the investigation of ankle changes that affect the sagittal plane and the possible relationship between balance and ankle movements in that plane.

Conflict of interest

None.

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