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Original research

An examination, correlation, and comparison of static and dynamic measures of postural stability in healthy, physically active adult

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ABSTRACT

Objective: To examine the relationship and differences between static and dynamic postural stability in healthy, physically active adults.
Design: Descriptive laboratory study.
Setting: Research laboratory.
Participants: Ten females (age: 21.6 ± 1.2 yrs, mass: 60.8 ± 7.6 kg, height: 165.0 ± 5.0 cm) and ten males (age: 25.1 ± 3.0 yrs, mass: 73.9 ± 8.7 kg, height: 173.5 ± 9.0 cm).
Main outcome measures: Static postural stability was measured during a single-leg standing task (standard deviation of the ground reaction forces). Dynamic postural stability was measured during a single-leg landing task using the Dynamic Postural Stability Index. Pearson's r-coefficients were calculated to examine relationships between the two tests and a one-way ANOVA was calculated to examine potential differences in test scores ($p < 0.05$).
Results: None of the Pearson's r-coefficients achieved statistical significance. The one-way ANOVA and post hoc comparisons demonstrated that dynamic postural stability scores were significantly higher than static postural stability scores.
Conclusions: A lack of a correlation between static and dynamic measures and increase in difficulty during dynamic measures indicates differences in the type and magnitude of challenge imposed by the different postural stability tasks. The more challenging dynamic measures of postural stability may be more suitable for prospective studies examining risk of ankle and knee injury in healthy, physically active individuals.

1. Introduction

Postural stability is 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 & Woollacott, 2001a). It is a dynamic process that requires sensory detection of body motions, integration of sensorimotor information within the central nervous system, and execution of appropriate musculoskeletal responses in order to establish an equilibrium between destabilizing and stabilizing forces (Riemann & Guskiewicz, 2000). The measurement of postural stability is critical to determining predictors of performance (Sell, Tsai, Smoliga, Myers, & Lephart, 2007), evaluating lower extremity musculoskeletal injuries (Ageberg, Roberts, Holmstrom, & Friden, 2005; Herrington, Hatcher, Hatcher, & McNicholas, 2009), determining the efficacy of physical training and rehabilitation techniques (Lephart, Myers, Sell, Tsai, & Bradley, 2007; Paterno, Myer, Ford, & Hewett, 2004; Rozzi, Lephart, Sterner, & Kuligowski, 1999; Verhagen et al., 2004), and injury prevention through the study of injury risk factors (Abt et al., 2007; McGuine & Keene, 2006; McHugh, Tyler, Tetro, Mullaney, & Nicholas, 2006; Rozzi, Lephart, & Fu, 1999; Rozzi, Lephart, Gear, & Fu, 1999; Soderman, Alfredson, Pietila, & Werner, 2001; Tyler, McHugh, Mirabella, Mullaney, & Nicholas, 2006). Numerous prospective studies have examined postural stability testing's capability to predict ankle joint injury (Beynnon, Renstrom, Alosa, Baumhauer, & Vacek, 2001; McGuine, Greene, Best, & Leverson, 2000; McKeon & Hertel, 2008a; Tropp, Ekstrand, & Gillquist, 1984; Wang, Chen, Shiang, Jan, & Lin, 2006; Willems, Witvrouw, Delbaere, Mahieu, et al., 2005; Willems, Witvrouw, Delbaere, Philippaerts, et al., 2005). Based on an examination of previous studies, static postural stability appears to be a predictor of acute lateral ankle sprains but the results are not "unanimous" (McKeon & Hertel, 2008a). The connection between postural stability deficits and predictors of knee injuries has not been established. One potential

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reason for the lack of evidence linking postural stability deficits to risk of knee injury, as well as the lack of "unanimous" results relative to ankle injury, may be the mode of testing. The majority of research has utilized static measures of postural stability which may not provide sufficient discriminatory and predictive capability compared to dynamic measures of postural stability.

Static postural stability can be defined as maintaining steadiness on a fixed, firm, unmoving base of support (Riemann, Caggiano, & Lephart, 1999). Steadiness has been defined as keeping the body as motionless as possible (Goldie, Bach, & Evans, 1989). Defining dynamic postural stability is more challenging. Goldie defined it as the ability to transfer the vertical projection of the center of gravity around the supporting base (Goldie et al., 1989). It has been measured following a perturbation of the support surface (Shultz et al., 2000), a perturbation of the individual (Hoffman, Schrader, & Koceja, 1999; Hoffman & Koceja, 1997), or requesting the individual to maintain his or her balance following a change in position or location (single-leg jump or landing) (Riemann et al., 1999; Ross & Guskiewicz, 2003; Wikstrom, Tillman, Smith, & Borsa, 2005). Recently there has been a shift away from static postural stability testing toward testing dynamic postural stability as it may be more functional and more applicable to an athletic population (Riemann et al., 1999). Commonly used measurements include the Multiple Single-Leg Hop–Stabilization test (Riemann et al., 1999), the Time to Stabilization test (Ross & Guskiewicz, 2003), the star-excursion test (Kinzey & Armstrong, 1998), and Dynamic Postural Stability Index (Wikstrom et al., 2005). The goal of all of these measurement techniques is to discover a more functional test that challenges a physically active population and uncovers underlying sensorimotor control issues in at-risk populations (injured, at risk for injury, or recovering from injury).

The identification of modifiable risk factors for ankle and knee musculoskeletal injury is a key component for overall injury reduction as well as the development of appropriate interventions (Mercy, Rosenberg, Powell, Broome, & Roper, 1993; Robertson, 1992). Knee and ankle injuries are some of the most common injuries that physically active individuals, athletes, and military personnel suffer. Postural stability testing has been employed in numerous studies examining the relationship between postural stability and risk of ankle injury (Beynnon et al., 2001; McGuine et al., 2000; Tropp et al., 1984; Watson, 1999; Willems, Witvrouw, Delbaere, Mahieu, et al., 2005; Willems, Witvrouw, Delbaere, Philippaerts, et al., 2005). While some of these studies have demonstrated that postural stability deficits can predict an increased risk of ankle injury (McGuine et al., 2000; Tropp et al., 1984; Watson, 1999; Willems, Witvrouw, Delbaere, Mahieu, et al., 2005), others have not (Beynnon et al., 2001; Willems, Witvrouw, Delbaere, Mahieu, et al., 2005; Willems, Witvrouw, Delbaere, Philippaerts, et al., 2005). The lack of consistent findings may be due to measures utilized (primarily static measures) which may not have the discriminatory capabilities necessary to predict risk of injury in a healthy population. The body of research examining postural stability as a risk factor for knee injury is significantly less than that of ankle injuries. The authors of the current study are aware of only two published research studies examining postural stability as a risk factor for knee injury (Paterno et al., 2010; Soderman et al., 2001) despite the fact that most knee injury prevention programs utilize postural stability training as a component training task (Caraffa, Cerulli, Projetti, Aisa, & Rizzo, 1996; Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Hewett, Stroupe, Nance, & Noyes, 1996; Lephart et al., 2005; Mandelbaum et al., 2005; Myklebust et al., 2003). The inconsistent link (predictive capability) between postural stability deficits and ankle and knee injury may be due to the type of postural stability test employed. In two different studies static postural stability has not been able to differentiate between groups of injured subjects (ankle and knee) while dynamic postural stability measures have (Hoffman et al., 1999; Ross & Guskiewicz, 2004). Furthermore, several authors have examined the correlation between static and dynamic postural stability measures in the same population and have demonstrated either a low correlation or no correlation at all between the two measures (Hoffman & Koceja, 1997; Hrysomallis, McLaughlin, & Goodman, 2006; Hubbard, Kramer, Denegar, & Hertel, 2007) Further research is necessary to determine the most appropriate postural stability test for utilization in prospective studies examining risk factors for ankle and knee injuries.

The primary purpose of the current study was to measure static and dynamic postural stability in young, healthy, physically active males and females to determine if a relationship exists between static and dynamic postural stability by examining the correlation between the two. A secondary purpose was to determine whether dynamic postural stability was more difficult to maintain than static postural stability by examining identical variables calculated across both static and dynamic conditions. Finally, the inter-session reliability of each of the postural stability tasks was also examined. A lack in correlation between the two conditions may indicate differences in responses to maintaining postural stability. Differences across conditions for identical variables will provide insight into ranked levels of imposed demand placed on the sensorimotor system and an individual's overall postural control capabilities. To the authors' knowledge, the inclusion of the selected variables across both static and dynamic conditions has not been previously investigated. Two tests of static postural stability were employed: an eyes closed and an eyes open condition while maintaining single-leg stance. The dynamic test of postural stability also incorporated two different tests (anterior-posterior and medial-lateral) that required the individual to stabilize themselves following a jump landing maneuver. It was hypothesized that no relationship would exist between the static and dynamic measures of postural stability and similar variables calculated across both conditions would be significantly higher during the dynamic postural stability tasks compared to the static postural stability tasks.

2. Methods

2.1. Subjects

A sample size estimate was performed a priori in order to determine the number of participants necessary to observe a significant correlation between the two measures of dynamic postural stability (Portney & Watkins, 2000). A total of 15 participants would be required in order to demonstrate a significant correlation (p-value$<$0.05, Power = 0.80, correlation coefficient = 0.60). A total of 20 physically active participants (10 males and 10 females) volunteered to take part in this study. Subject demographics are provided in Table 1. "Physically active" was defined as participating in physical activity, such as jogging, cycling, lifting, and other non-competitive sports, at least three times per week for a minimum of 30 min each session. Participants reported no history of back or lower extremity surgery, no back or

Table 1
Subject demographics.

	Males (n = 10)		Females (n = 10)		Total (n = 20)	
	Mean	±SD	Mean	±SD	Mean	±SD
Age (yrs)	25.1	3.0	21.6	1.2	23.4	2.9
Height (cm)	173.5	9.0	165.0	5.0	169.3	8.3
Mass (kg)	73.9	8.7	60.8	7.6	67.3	10.5

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lower extremity injury within six months prior to testing, no neurological or vascular compromise, no training in balance and jump landings, and no known pregnancy at the time of testing (female subjects). All participants read and signed an informed consent form approved by the University's Institutional Review Board.

2.2. *Equipment and procedures*

A force plate (Kistler 9286A, Amherst, NY) was used to collect ground reaction force data (1200 Hz) during all tasks. Subjects reported for two test sessions with a minimum of 48 h and maximum of 72 h between sessions in order to calculate inter-session reliability across all measures. The first test session was utilized for the comparisons between the static and dynamic postural stability tasks. Static postural stability was assessed using two static balance tasks: 1) eyes open (EO) and 2) eyes closed (EC) based on Goldie et al. (Goldie et al., 1989; Goldie, Evans, & Bach, 1992) The protocol incorporates touch downs on the force plate during data analysis and has been demonstrated to be valid and reliable (Goldie et al., 1989; Goldie et al., 1992; Sell, Ferris, et al., 2007; Sell, Tsai, et al., 2007). For the static balance task, participants assumed single-leg stance on their dominant leg (preferred kicking foot) and placed their hands on their hips. The non-stance (non-dominant) leg was flexed at the knee and hip as to bring the non-stance foot to the height of the contralateral ankle. Participants were instructed to immediately lift their non-stance leg back into test position if it touched down on the force plate. Trials were discarded and recollected if the participant's non-stance limb touched the stance limb or the ground around the force plate. A total of three 10 s trials were conducted with 30 s of rest between trials. All subjects performed the eyes closed condition prior to the eyes open condition. This identical protocol has been used previously and determined to be reliable (Sell, Ferris, et al., 2007; Sell, Tsai, et al., 2007). Participants were allowed to rest while standing on both legs between trials and were given two practice trials for each condition.

Dynamic postural stability was assessed using two dynamic tasks: 1) anterior-posterior (AP) jump and 2) medial-lateral (ML) jump. Jump protocols were based on Wikstrom et al and Ross et al (Ross, Guskiewicz, & Yu, 2005; Wikstrom et al., 2005). Modifications included normalization to jump distance rather than jump height similar to Padua et al (Padua et al., 2009) in order to minimize the equipment necessary for potential remote testing (future research) and to incorporate greater deceleration forces (posterior ground reaction forces) (Sell, Ferris, et al., 2007; Sell, Tsai, et al., 2007). For the AP jump participants were instructed to stand on two legs at a distance of 40% of their body height from the force plate. Participants were instructed to jump forward over a 12-inch hurdle to the force plate and land on their dominant leg, stabilize as quickly as possible, and balance for 10 s with their hands on their hips (Fig. 2). For the ML jump participants were instructed to stand at a distance equal to 33% of their body height away from the force plate (Fig. 3). Participants were instructed to jump laterally over a 6-inch hurdle to the force plate and land on their test leg, stabilize as quickly as possible, and balance for 10 s with their hands on their hips. For both dynamic tasks, upper extremity movement was unrestricted but participants were asked to quickly place their hands on their hips only after stabilizing. Trials were discarded and recollected if the participant's non-stance limb touched the stance limb or the ground around the force plate. All of the subjects performed the AP jump first. Five successful trials were collected and used for data analysis for both dynamic tasks.

2.3. *Data reduction and statistical analysis*

A custom MATLAB (v7.0.4, Natick, MA) script file was used to process data. Data were passed through a zero-lag 4th order low pass Butterworth filter with a 20 Hz cutoff frequency. The primary variables for the static postural stability trials were standard deviation of the ground reaction forces in the anterior-posterior, medial-lateral, and vertical direction (AP stdev, ML stdev, and V stdev, respectively) throughout each 10 s trial (Goldie et al., 1989; Goldie et al., 1992). Although there are arguments that increased variability in movement may indicate the ability of an individual to adapt to unique constraints (Davids, Glazier, Araujo, & Bartlett, 2003), within the context of the current protocol and data analysis, increased variability demonstrates decreased postural stability (Goldie et al., 1992). Goldie et al previously demonstrated that as balance condition difficulty increased the standard deviation of the ground reaction forces also increased. A total of three trials were averaged and used for final analysis. In prior laboratory piloting and testing, three trials were demonstrated to be highly reliable for the static balance tasks (ICC = 0.759–0.879; SEM = 0.187–1.616) (Sell, Ferris, et al., 2007; Sell, Tsai, et al., 2007). The primary variable for the AP jump and ML jump was the Dynamic Postural Stability Index (DPSI) depicted in Fig. 1. DPSI was computed using the first 3 s of the ground reaction forces following initial contact identified as the instant the vertical ground reaction force exceeded 5% body weight. DPSI is a composite of AP, ML, and V ground reaction forces demonstrated to possess good reliability (Wikstrom et al., 2005). Similar to the static postural stability task, a higher DPSI represents worse postural stability. A total of five trials were averaged and used for final analyses. In addition to the primary variables, similar variables were calculated across all of the postural stability tests. Specifically, AP stdev, ML stdev, and V stdev were calculated during the first 10 s of the dynamic tasks and DPSI during the first 3 s of each of the static tests. These additional calculations allowed for comparisons of similar variables across all dynamic and static postural stability tasks.

Inter-session reliability and standard errors of measurement were calculated for the primary measures during both postural stability tasks. An intraclass correlation (ICC), using the (3,k) model described by Shrout and Fleiss was employed to determine the inter-session reliability (Shrout & Fleiss, 1979). A series of 12 bivariate correlations (Pearson's r) were computed to determine if a relationship exists between the static and dynamic postural stability measures. A one-way analysis of variance (ANOVA) was performed for each variable across all postural stability measures to determine if there was a significant difference (level of difficulty). Multiple comparisons were made post-hoc with a Bonferroni correction for *p*-values when the one-way ANOVA demonstrated statistical significance. An alpha level of 0.05 was set a priori to determine significance for all statistical analyses.

$$\text{DPSI} = \left(\sqrt{\frac{\Sigma(0\text{-GRFx})^2 + \Sigma(0\text{-GRFy})^2 + \Sigma(\text{body weight-GRFz})^2}{\text{number of data points}}} \right) \div \text{body weight}$$

Fig. 1. Calculation for the dynamic postural stability index (DPSI).

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Fig. 2. Modified anterior-posterior (AP) jump over a 12" hurdle to assess dynamic postural stability.

3. Results

The means, standard deviations, and 95% confidence intervals for the AP stdev, ML stdev, and V stdev for the static postural stability tasks and the DPSI scores for the two dynamic postural stability tasks are presented in Table 2. The inter-session reliability and standard errors of measurement are provided in Table 3. Overall, good inter-session reliability was demonstrated for both static and dynamic measures of postural stability. The computed Pearson correlation coefficients and corresponding *p*-values are presented in Table 4. None of the 12 comparisons achieved statistical significance. The results of the one-way ANOVA including 95% confidence intervals, Power, and Effect Size for the post hoc tests are presented in Table 5. In general (with one exception), the values for all variables calculated across all tasks were significantly lower during the static postural stability tasks compared to the dynamic postural stability tasks. The exception, the ML stdev during the static postural stability-eyes closed condition was lower than dynamic postural stability-ML jump but the comparison was not statistically significant.

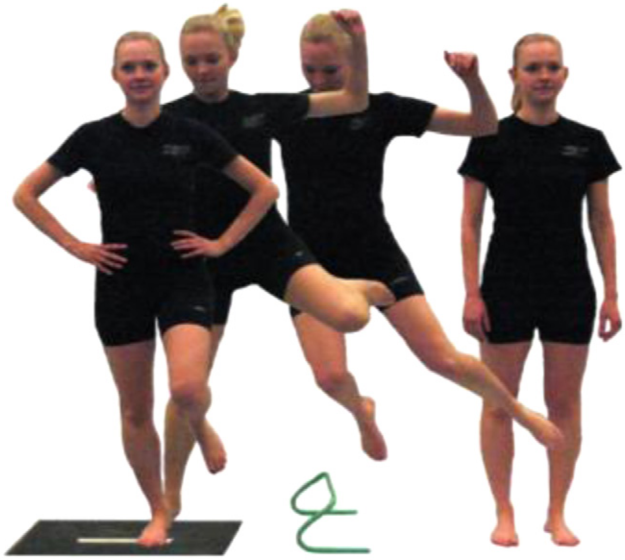

Fig. 3. Modified medial-lateral (ML) jump over a 6" hurdle to assess dynamic postural stability.

Table 2
Primary variables for static and dynamic postural stability.

	Mean	±SD	95% CI	
Static postural stability-eyes open (AP standard deviation)	2.028	0.651	1.723	2.332
Static postural stability-eyes open (ML standard deviation)	2.376	0.995	1.910	2.841
Static postural stability-eyes open (V standard deviation)	3.080	1.765	2.254	3.906
Static postural stability-eyes closed (AP standard deviation)	4.330	1.198	3.769	4.890
Static postural stability-eyes closed (ML standard deviation)	6.346	2.806	5.033	7.659
Static postural stability-eyes closed (V standard deviation)	7.436	3.735	5.688	9.184
Dynamic postural stability-AP jump-DPSI	0.348	0.035	0.332	0.364
Dynamic postural stability-ML jump DPSI	0.316	0.035	0.299	0.332

4. Discussion

The primary purpose of the study was to examine the relationship between static and dynamic postural stability in a healthy group of subjects. The secondary purpose was to compare the difficulty in maintaining dynamic postural stability compared to static postural stability. We hypothesized that there would be no relationship between static postural stability test measures and dynamic postural stability test measures indicating differences in responses and potential increasing challenge in the dynamic postural stability test compared to the static postural stability test. We also hypothesized that similar measures calculated across all conditions would increase in the dynamic postural stability tests indicating greater difficulty in maintaining postural stability. The results of the statistical analysis support both of these hypotheses. There were no significant relationships in the primary variables between static and dynamic postural stability tests and measures, and in general, they were significantly higher during the dynamic postural stability tests compared to the static postural stability tests.

A comparison between the results of our study to previous literature is somewhat limiting as there are only a few studies that have captured both static and dynamic measures of postural stability within one study on a healthy population (Hoffman & Koceja, 1997; Hrysomallis et al., 2006). Hoffman and Koceja developed a reliable dynamic balance test that incorporated an

Table 3
Inter-session reliability for static and dynamic postural stability measures.

	ICC	SEM
Static postural stability - eyes open (AP standard deviation)	0.90	0.19
Static postural stability - eyes open (ML standard deviation)	0.94	0.23
Static postural stability - eyes open (V standard deviation)	0.93	0.41
Static postural stability - eyes closed (AP standard deviation)	0.77	0.87
Static postural stability - eyes closed (ML standard deviation)	0.73	1.79
Static postural stability - eyes closed (V standard deviation)	0.71	3.40
Dynamic postural stability - AP jump - DPSI	0.86	0.01
Dynamic postural stability - ML jump - DPSI	0.92	0.01

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Table 4
Pairwise correlations between static and dynamic postural stability measures (r-coefficient (*p*-value)).

	DPSI AP jump	DPSI ML jump
Static postural stability - eyes open (AP standard deviation)	0.16 (0.50	0.23 (0.34)
Static postural stability - eyes open (ML standard deviation)	0.05 (0.82)	0.06 (0.79)
Static postural stability - eyes open (V standard deviation)	−0.13 (0.59)	−0.10 (0.68)
Static postural stability - eyes closed (AP standard deviation)	0.05 (0.82)	0.12 (0.62)
Static postural stability - eyes closed (ML standard deviation)	0.15 (0.52)	0.21 (0.37)
Static postural stability - eyes closed (V standard deviation)	0.09 (0.70)	0.21 (0.36)

electrically induced perturbation of the ankle musculature in healthy adults (Hoffman & Koceja, 1997). Similar to the results of the current study, they demonstrated no correlation between static measures of sway and their dynamic assessment of postural control. Hrysomallis et al. examined single limb balance and a dynamic balance task in healthy, professional footballers and demonstrated low correlations between the two tests (Hrysomallis et al., 2006). More studies examining both dynamic and static postural stability have been performed in groups of individuals who have suffered injury. Hoffman et al. examined the single-leg static and dynamic postural control compared to a healthy group in subjects who had undergone anterior cruciate ligament reconstruction and were functionally stable (Hoffman et al., 1999). Subjects demonstrated no differences in static postural control but had significant differences in dynamic postural stability compared to the healthy group. Ross and Guskiewicz demonstrated similar results in individuals who had functional ankle instability (FAI) compared to a healthy group (Ross & Guskiewicz, 2004). The FAI group did not demonstrate differences in static postural stability compared to the healthy group but did demonstrate worse dynamic postural stability. Neither of the previous two studies examined correlations between the two measures. One study by Hubbard et al. did examine correlations between static and dynamic postural stability measures in a group of individuals with chronic ankle instability (Hubbard et al., 2007). No significant correlations were revealed between the two measures.

The lack of correlation between the two different conditions is likely due to the challenge imposed on the systems necessary for maintenance of postural stability. Maintenance of postural stability during both dynamic and static conditions involves establishing an equilibrium between destabilizing and stabilizing forces (McCollum & Leen, 1989) and requires sensory information derived from vision, the vestibular systems, and somatosensory feedback (Riemann & Guskiewicz, 2000). Multiple systems contribute to maintenance of postural control, including musculoskeletal components, internal representations, adaptive mechanisms, anticipatory mechanisms, sensory strategies, individual sensory systems, and neuromuscular synergies (Shumway-Cook & Woollacott, 2001b). During typical static balance testing, the individual establishes the base of support prior to testing and must maintain the center of mass within the base of support throughout the timed test. The destabilizing forces and the demands on those systems that contribute to maintenance of postural control are minimal, and unless one of these systems has been compromised by injury or pathology, it is a relatively rudimentary task (the static postural stability test). But, if one of these systems has been compromised, you may observe altered postural control strategies with effects observed in test measurements. For example, static postural stability testing has been utilized effectively in populations with ankle injury and chronic ankle instability in order to differentiate between injury and non-injury (McKeon & Hertel, 2008a, 2008b). Dynamic postural stability tasks pose a greater challenge

Table 5
Comparisons of all variables across all postural stability tasks.

Variable		*p*-value for post hoc comparison	95% CI first variable		95% CI second variable		Power	Effect size
AP StDev	SPS EO (2.028 ± 0.651) vs SPS EC (4.330 ± 1.198)	1.000	1.723	2.332	3.769	4.890	1.000	0.767
	SPS EO (2.028 ± 0.651) vs DPS - AP (41.672 ± 11.737)	$p < 0.001$	1.723	2.332	36.180	47.165	1.000	0.922
	SPS EO (2.028 ± 0.651) vs DPS - ML (10.218 ± 2.090)	$p < 0.001$	1.723	2.332	9.240	11.196	1.000	0.935
	SPS EC (4.330 ± 1.198) vs DPS - AP (41.672 ± 11.737)	$p < 0.001$	3.769	4.890	36.180	47.165	1.000	0.913
	SPS EC (4.330 ± 1.198) vs DPS - ML (10.218 ± 2.090)	0.016	3.769	4.890	9.240	11.196	1.000	0.866
	DPS - AP (41.672 ± 11.737) vs DPS - ML (10.218 ± 2.090)	$p < 0.001$	36.180	47.165	9.240	11.196	1.000	0.881
	one-way ANOVA: $p < 0.001$; $F(3,76) = 188.12$							
ML StDev	SPS EO (2.376 ± 0.995) vs SPS EC (6.346 ± 2.806)	0.023	1.910	2.841	5.033	7.659	1.000	0.686
	SPS EO (2.376 ± 0.995) vs DPS - AP (8.362 ± 2.584)	$p < 0.001$	1.910	2.841	7.152	9.571	1.000	0.837
	SPS EO (2.376 ± 0.995) vs DPS - ML (37.608 ± 7.428)	$p < 0.001$	1.910	2.841	34.131	41.085	1.000	0.958
	SPS EC (6.346 ± 2.806) vs DPS - AP (8.362 ± 2.584)	0.802	5.033	7.659	7.152	9.571	0.657	0.941
	SPS EC (6.346 ± 2.806) vs DPS - ML (37.608 ± 7.428)	$p < 0.001$	5.033	7.659	34.131	41.085	1.000	0.941
	DPS - AP (8.362 ± 2.584) vs DPS - ML (37.608 ± 7.428)	$p < 0.001$	7.152	9.571	34.131	41.085	1.000	0.935
	one-way ANOVA: $p < 0.001$; $F(3,76) = 295.03$							
V StDev	SPS EO (3.080 ± 1.765) vs SPS EC (7.436 ± 3.735)	1.000	2.254	3.906	5.688	9.184	0.997	0.598
	SPS EO (3.080 ± 1.765) vs DPS - AP (94.664 ± 27.638)	$p < 0.001$	2.254	3.906	81.729	107.599	1.000	0.919
	SPS EO (3.080 ± 1.765) vs DPS - ML (89.467 ± 19.596)	$p < 0.001$	2.254	3.906	80.296	98.638	1.000	0.952
	SPS EC (7.436 ± 3.735) vs DPS - AP (94.664 ± 27.638)	$p < 0.001$	5.688	9.184	81.729	107.599	1.000	0.911
	SPS EC (7.436 ± 3.735) vs DPS - ML (89.467 ± 19.596)	$p < 0.001$	5.688	9.184	80.296	98.638	1.000	0.946
	DPS - AP (94.664 ± 27.638) vs DPS - ML (89.467 ± 19.596)	1.000	81.729	107.599	80.296	98.638	0.105	0.108
	one-way ANOVA: $p < 0.001$; $F(3,76) = 173.03$							
DPSI	SPS EO (0.014 ± 0.018) vs SPS EC (0.019 ± 0.008)	1.000	0.005	0.022	0.015	0.022	0.206	0.177
	SPS EO (0.014 ± 0.018) vs DPS - AP (0.348 ± 0.035)	$p < 0.001$	0.005	0.022	0.332	0.364	1.000	0.986
	SPS EO (0.014 ± 0.018) vs DPS - ML (0.316 ± 0.035)	$p < 0.001$	0.005	0.022	0.299	0.332	1.000	0.983
	SPS EC (0.019 ± 0.008) vs DPS - AP (0.348 ± 0.035)	$p < 0.001$	0.015	0.022	0.332	0.364	1.000	0.988
	SPS EC (0.019 ± 0.008) vs DPS - ML (0.316 ± 0.035)	$p < 0.001$	0.015	0.022	0.299	0.332	1.000	0.986
	DPS - AP (0.348 ± 0.035) vs DPS - ML (0.316 ± 0.035)	0.002	0.332	0.364	0.299	0.332	0.824	0.416
	one-way ANOVA: $p < 0.001$; $F(3,76) = 942.38$							

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to those systems involved in postural stability and in the case of the current measure also include greater destabilizing forces (ground reaction forces, joint forces and muscle forces) that must be countered. The significant differences observed between the dynamic and postural stability tasks for similar variables demonstrates that the static postural stability tests utilized in the current study imposes external destabilizing forces of a lower magnitude and/or did not provide the same challenge to those systems involved in postural control as compared to dynamic tests examined.

5. Applicability

The results of this study have important implications for injury prevention research. The lack of a correlation between the static and dynamic measures of postural stability employed in the current study indicates different responses for maintaining postural stability and/or different stresses to systems necessary for maintenance of postural stability. Additionally, the significant differences in similar variables across both sets of measures demonstrate that the dynamic measures of postural stability were more difficult or more challenging. These differences may indicate that measures of postural stability (static versus dynamic) should be carefully chosen based on the population to be studied. In our opinion, the greater challenge posed by dynamic measures of postural stability may indicate they are a better tool for prospectively analyzing risk factors for ankle/knee injury in athletic populations who likely have highly developed sensorimotor systems (Lephart, Giraldo, Borsa, & Fu, 1996).

6. Conclusions

The current study demonstrated a lack of correlation between static and dynamic measures of postural stability as well as increasing difficulty during dynamic postural stability measures. The lack of a correlation between the two different measures and a significant difference in similar measures between the two conditions indicate differences in the type and magnitude of challenge imposed on the systems necessary for maintenance of postural stability. Both measures are likely useful depending on the population to be studied. In our opinion the dynamic measures are more appropriate for healthy, athletic populations. Future research should focus on the capability of both measures of postural stability to predict lower extremity injury risk in these populations.

Conflict of interest

None declared.

Ethical approval

All participants read and signed an informed consent form approved by the University's Institutional Review Board.

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References

Abt, J. P., Sell, T. C., Laudner, K. G., McCrory, J. L., Loucks, T. L., Berga, S. L., et al. (2007). Neuromuscular and biomechanical characteristics do not vary across the menstrual cycle. *Knee Surgery, Sports Traumatology, Arthroscopy, 15*, 901–907.

Ageberg, E., Roberts, D., Holmstrom, E., & Friden, T. (2005). Balance in single-limb stance in patients with anterior cruciate ligament injury: relation to knee laxity, proprioception, muscle strength, and subjective function. *American Journal of Sports Medicine, 33*, 1527–1535.

Beynnon, B. D., Renstrom, P. A., Alosa, D. M., Baumhauer, J. F., & Vacek, P. M. (2001). Ankle ligament injury risk factors: a prospective study of college athletes. *Journal of Orthopaedic Research, 19*, 213–220.

Caraffa, A., Cerulli, G., Projetti, M., Aisa, G., & Rizzo, A. (1996). Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. *Knee Surgery, Sports Traumatology, Arthroscopy, 4*, 19–21.

Davids, K., Glazier, P., Araujo, D., & Bartlett, R. (2003). Movement systems as dynamical systems: the functional role of variability and its implications for sports medicine. *Sports Medicine, 33*, 245–260.

Goldie, P. A., Bach, T. M., & Evans, O. M. (1989). Force platform measures for evaluating postural control: reliability and validity. *Archives of Physical Medicine and Rehabilitation, 70*, 510–517.

Goldie, P. A., Evans, O. M., & Bach, T. M. (1992). Steadiness in one-legged stance: development of a reliable force- platform testing procedure. *Archives of Physical Medicine and Rehabilitation, 73*, 348–354.

Herrington, L., Hatcher, J., Hatcher, A., & McNicholas, M. (2009). A comparison of star excursion balance test reach distances between ACL deficient patients and asymptomatic controls. *Knee, 16*, 149–152.

Hewett, T. E., Lindenfeld, T. N., Riccobene, J. V., & Noyes, F. R. (1999). The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *American Journal of Sports Medicine, 27*, 699–706.

Hewett, T. E., Stroupe, A. L., Nance, T. A., & Noyes, F. R. (1996). Plyometric training in female athletes. Decreased impact forces and increased hamstring torques. *American Journal of Sports Medicine, 24*, 765–773.

Hoffman, M. A., & Koceja, D. M. (1997). Dynamic balance testing with electrically evoked perturbation: A test of reliability. *Archives of Physical Medicine and Rehabilitation, 78*, 290–293.

Hoffman, M., Schrader, J., & Koceja, D. (1999). An investigation of postural control in postoperative anterior cruciate ligament reconstruction patients. *Journal of Athletic Training, 34*, 130–136.

Hrysomallis, C., McLaughlin, P., & Goodman, C. (2006). Relationship between static and dynamic balance tests among elite Australian footballers. *Journal of Sports Science and Medicine, 9*, 288–291.

Hubbard, T. J., Kramer, L. C., Denegar, C. R., & Hertel, J. (2007). Contributing factors to chronic ankle instability. *Foot & Ankle International, 28*, 343–354.

Kinzey, S. J., & Armstrong, C. W. (1998). The reliability of the star-excursion test in assessing dynamic balance. *Journal of Orthopaedic & Sports Physical Therapy, 27*, 356–360.

Lephart, S. M., Abt, J. P., Ferris, C. M., Sell, T. C., Nagai, T., Myers, J. B., et al. (2005). Neuromuscular and biomechanical characteristic changes in high school athletes: a plyometric versus basic resistance program. *British Journal of Sports Medicine, 39*, 932–938, December.

Lephart, S. M., Giraldo, J. L., Borsa, P. A., & Fu, F. H. (1996). Knee joint proprioception: a comparison between female intercollegiate gymnasts and controls. *Knee Surgery, Sports Traumatology, Arthroscopy, 4*, 121–124.

Lephart, S. M., Myers, J. B., Sell, T. C., Tsai, Y. S., & Bradley, J. P. (2007). Golf injury prevention: an orthopedic approach through physical testing, biomechanics, and training. In *American Academy of Orthopaedic Surgeons Annual Meeting. San Diego, CA*.

Mandelbaum, B. R., Silvers, H. J., Watanabe, D. S., Knarr, J. F., Thomas, S. D., Griffin, L. Y., et al. (2005). Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *American Journal of Sports Medicine, 33*, 1003–1010.

McCollum, G., & Leen, T. (1989). The form and exploration of mechanical stability limits in erect stance. *The Journal of Motor Behavior, 21*, 225–238.

McGuine, T. A., Greene, J. J., Best, T., & Leverson, G. (2000). Balance as a predictor of ankle injuries in high school basketball players. *Clinical Journal of Sport Medicine, 10*, 239–244.

McGuine, T. A., & Keene, J. S. (2006). The effect of a balance training program on the risk of ankle sprains in high school athletes. *American Journal of Sports Medicine, 34*, 1103–1111.

McHugh, M. P., Tyler, T. F., Tetro, D. T., Mullaney, M. J., & Nicholas, S. J. (2006). Risk factors for noncontact ankle sprains in high school athletes: the role of hip strength and balance ability. *American Journal of Sports Medicine, 34*, 464–470.

McKeon, P. O., & Hertel, J. (2008a). Systematic review of postural control and lateral ankle instability, part I: can deficits be detected with instrumented testing. *Journal of Athletic Training, 43*, 293–304.

McKeon, P. O., & Hertel, J. (2008b). Systematic review of postural control and lateral ankle instability, part II: is balance training clinically effective? *Journal of Athletic Training, 43*, 305–315.

Mercy, J. A., Rosenberg, M. L., Powell, K. E., Broome, C. V., & Roper, W. L. (1993). Public health policy for preventing violence. *Health Affairs, 12*, 7–29.

Myklebust, G., Engebretsen, L., Braekken, I. H., Skjolberg, A., Olsen, O. E., & Bahr, R. (2003). Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clinical Journal of Sport Medicine, 13*, 71–78.

Padua, D. A., Marshall, S. W., Boling, M. C., Thigpen, C. A., Garrett, W. E., Jr., & Beutler, A. I. (2009). The Landing Error Scoring System (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: The JUMP-ACL study. *American Journal of Sports Medicine, 37*, 1996–2002.

Paterno, M. V., Myer, G. D., Ford, K. R., & Hewett, T. E. (2004). Neuromuscular training improves single-limb stability in young female athletes. *Journal of Orthopaedic & Sports Physical Therapy, 34*, 305–316.

Paterno, M. V., Schmitt, L. C., Ford, K. R., Rauh, M. J., Myer, G. D., Huang, B., & Hewett, T. E. (2010). Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. *American Journal of Sports Medicine, 38*, 1968–1978.

Portney, L. G., & Watkins, M. P. (2000). *Foundations of clinical research: Applications to practice* (2nd ed.). Upper Saddle River, NJ: Prentice Hall.

Riemann, B. L., Caggiano, N. A., & Lephart, S. M. (1999). Examination of a clinical method of assessing postural control during a functional performance task. *Journal of Sport Rehabilitation, 8*, 171–183.

Riemann, B. L., & Guskiewicz, K. (2000). Contribution of the peripheral somatosensory system to balance and postural equilibrium. In S. M. Lephart, & F. H. Fu (Eds.), *Proprioception and neuromuscular control in joint stability* (pp. 37–51). Champaign, IL: Human Kinetics.

Robertson, L. S. (1992). *Injury epidemiology*. New York: Oxford University Press.

Ross, S., & Guskiewicz, K. M. (2003). Time to stabilization: a method for analyzing dynamic. *Athletic Therapy Today, 8*, 37–39.

Ross, S. E., & Guskiewicz, K. M. (2004). Examination of static and dynamic postural stability in individuals with functionally stable and unstable ankles. *Clinical Journal of Sport Medicine, 14*, 332–338.

Ross, S. E., Guskiewicz, K. M., & Yu, B. (2005). Single-leg jump-landing stabilization times in subjects with functionally unstable ankles. *Journal of Athletic Training, 40*, 298–304.

Rozzi, S. L., Lephart, S. M., & Fu, F. H. (1999). Effects of muscular fatigue on knee joint laxity and neuromuscular characteristics of male and female athletes. *Journal of Athletic Training, 34*, 106–114.

Rozzi, S. L., Lephart, S. M., Gear, W. S., & Fu, F. H. (1999). Knee joint laxity and neuromuscular characteristics of male and female soccer and basketball players. *American Journal of Sports Medicine, 27*, 312–319.

Rozzi, S. L., Lephart, S. M., Sterner, R., & Kuligowski, L. (1999). Balance training for persons with functionally unstable ankles. *Journal of Orthopaedic & Sports Physical Therapy, 29*, 478–486.

Sell, T. C., Ferris, C. M., Abt, J. P., Tsai, Y. S., Myers, J. B., Fu, F. H., & Lephart, S. M. (2007). Predictors of proximal anterior tibia shear force during a vertical stop-jump. *Journal of Orthopaedic Research, 25*, 1589–1597.

Sell, T. C., Tsai, Y. S., Smoliga, J. M., Myers, J. B., & Lephart, S. M. (2007). Strength, flexibility, and balance characteristics of highly proficient golfers. *The Journal of Strength & Conditioning Research, 21*, 1166–1171.

Shrout, P. E., & Fleiss, J. L. (1979). Intraclass correlations: uses in assessing rater reliability. *Psychological Bulletin, 86*, 420–428.

Shultz, S. J., Perrin, D. H., Adams, J. M., Arnold, B. L., Gansneder, B. M., & Granata, K. P. (2000). Assessment of neuromuscular response characteristics at the knee following a functional perturbation. *Journal of Electromyography and Kinesiology, 10*, 159–170.

Shumway-Cook, A., & Woollacott, M. H. (2001a). *Motor control: Theory and practical applications* (2nd ed.). Philadelphia: Lippincott Williams & Wilkins.

Shumway-Cook, A., & Woollacott, M. H. (2001b). Postural control. In M. Biblis (Ed.), *Motor control: Theory and practical applications* (2nd ed.). (pp. 163–191) Philadelphia: Lippincott Williams & Wilkins.

Soderman, K., Alfredson, H., Pietila, T., & Werner, S. (2001). Risk factors for leg injuries in female soccer players: a prospective investigation during one outdoor season [comment]. *Knee Surgery, Sports Traumatology, Arthroscopy, 9*, 313–321.

Tropp, H., Ekstrand, J., & Gillquist, J. (1984). Stabilometry in functional instability of the ankle and its value in predicting injury. *Medicine & Science in Sports & Exercise, 16*, 64–66.

Tyler, T. F., McHugh, M. P., Mirabella, M. R., Mullaney, M. J., & Nicholas, S. J. (2006). Risk factors for noncontact ankle sprains in high school football players: the role of previous ankle sprains and body mass index. *American Journal of Sports Medicine, 34*, 471–475.

Verhagen, E., van der Beek, A., Twisk, J., Bouter, L., Bahr, R., & van Mechelen, W. (2004). The effect of a proprioceptive balance board training program for the prevention of ankle sprains: a prospective controlled trial. *American Journal of Sports Medicine, 32*, 1385–1393.

Wang, H. K., Chen, C. H., Shiang, T. Y., Jan, M. H., & Lin, K. H. (2006). Risk-factor analysis of high school basketball-player ankle injuries: a prospective controlled cohort study evaluating postural sway, ankle strength, and flexibility. *Archives of Physical Medicine and Rehabilitation, 87*, 821–825.

Watson, A. W. (1999). Ankle sprains in players of the field-games Gaelic football and hurling. *Journal of Sports Medicine and Physical Fitness, 39*, 66–70.

Wikstrom, E. A., Tillman, M. D., Smith, A. N., & Borsa, P. A. (2005). A new force-plate technology measure of dynamic postural stability: the dynamic postural stability index. *Journal of Athletic Training, 40*, 305–309.

Willems, T. M., Witvrouw, E., Delbaere, K., Mahieu, N., De Bourdeaudhuij, I., & De Clercq, D. (2005). Intrinsic risk factors for inversion ankle sprains in male subjects: a prospective study. *Journal of Sports Medicine, 33*, 415–423.

Willems, T. M., Witvrouw, E., Delbaere, K., Philippaerts, R., De Bourdeaudhuij, I., & De Clercq, D. (2005). Intrinsic risk factors for inversion ankle sprains in females–a prospective study. *Scandinavian Journal of Medicine & Science in Sports, 15*, 336–345.

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