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Comparison and Correlation of Dynamic Postural Stability Indices Obtained during Different Dynamic Landing Tasks and Footwear Conditions

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Abstract

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Design: Cross-sectional.

Setting: Research laboratory.

Participants: Twenty-five physically active adults (13 males/12 females, age: 22.1±4.2yrs, height: 178.3±11.1cm, weight: 75.6±19.4kg).

Main Outcome Measures: Subjects jumped off two feet and landed with their preferred foot on a force-plate. From the ground reaction forces, the DPSI scores in the anterior-posterior, medial-lateral, and vertical directions, and the cumulative scores (DPSI) were calculated under two protocols and footwear conditions. Based on normality of data distribution, paired t-tests/Wilcoxon signed rank tests and Pearson/Spearman correlation coefficients were used to compare, and measure the relationship between the two protocols under two footwear conditions ($p<0.05$).

Results: There were mixed results for DPSI scores when comparing the two protocols. There were significant differences ($p=0.001–0.039$) and positive correlations ($r=0.660–0.870$, $p<0.001$) on the DPSI scores between footwear conditions during the NDP protocol while the RWDP showed no significant differences.

Conclusions: Different protocols and footwear conditions may impact DPSI scores. Therefore, a standardized protocol and footwear condition should be established for future studies examining dynamic postural stability.

Keyword: Dynamic postural stability, footwear, landing protocols

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Conclusions: *Different protocols and footwear conditions may impact DPSI scores. Therefore, a standardized protocol and footwear condition should be established for future studies examining dynamic postural stability.*

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Highlights:

- The APSI and MLSI scores were significantly different between two protocols.
- The DPSI scores were significantly different between footwear conditions during the NDP protocol.
- A standardized protocol and footwear should be used when possible.

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Introduction

Postural stability can be 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 (Sell, House, Abt, Huang, & Lephart, 2012). Postural stability has been found to be influenced by three main systems: vision, vestibular, and somatosensory (Chaudhry et al., 2004; Riemann, Guskiewicz, & Shields, 1999). Postural stability can be divided into two categories: static postural stability and dynamic postural stability. Static postural stability is defined as maintaining steadiness on a fixed, firm, unmoving base of support (Riemann, Caggiano, & Lephart, 1999). Dynamic postural stability is defined as an individual's ability to maintain balance while transitioning from a dynamic to a static state (Goldie, Bach, & Evans, 1989). Dynamic postural stability testing using a single leg jump landing and the Dynamic Postural Stability Index (DPSI) is a growing area of investigation due to its proposed ability to detect differences between individuals with stable and unstable ankle joints during dynamic tests (Ross & Guskiewicz, 2003). Investigators have found multiple uses for the DPSI in the clinical and laboratory setting including injury evaluation, post treatment levels, and as a baseline test for ankle stability in athletes (Sell et al., 2012; Wikstrom, Tillman, Smith, & Borsa, 2005; Willems, Witvrouw, Delbaere, Mahieu, et al., 2005; Willems, Witvrouw, Delbaere, Philippaerts, et al., 2005). With these abilities, DPSI testing has the potential to be incorporated into clinical practices to aid in rehabilitation and as a preventative test to identify postural stability deficits.

There are two common single leg jump landing protocols that are quantified with DPSI: the Ross and Wikstrom DPSI Protocol (RWDP) (Ross & Guskiewicz, 2003; Wikstrom et al., 2005) and the Neuromuscular Research Laboratory DPSI Protocol (NDP) (Sell et al., 2012). These protocols are both single leg jump landing tasks but differ in jump height, jump distance, arm mechanics, and attention that may lead to a difference in DPSI scores (Heebner, 2015; Kerr, Condon, & McDonald, 1985; Santello, McDonagh, & Challis, 2001). A significant difference in scores makes DPSI results from varying protocols difficult to compare. It is important to have comparable data across the literature in order to build a strong base of knowledge regarding dynamic postural stability. Therefore, this study compared the DPSI scores between the RWDP and NDP protocols and establish the relationship between the two protocols.

Across the RWDP and the NDP, there is also no footwear recommendation. As for results, there have been studies completed in athletic shoes (shod) and studies completed barefoot during the postural stability testing. Footwear has been seen to have a significant effect on DPSI scores within participants (Whitehead et al., 2014). Participants have significantly different DPSI scores when they were wearing three different footwear: athletic shoes, military boots, and minimalist footwear during the NDP (Whitehead et al., 2014). With the significant effect of footwear on DPSI scores, it is important to standardize footwear across all dynamic postural stability testing in order to maintain comparability. However, it is nearly impossible to provide all participants with the same pair of shoes across all studies. One way to solve this issue and standardize the single leg jump landing protocols is to collect them barefoot. For these reasons, this study compared the DPSI scores between shod and barefoot conditions to establish the relationship between the two conditions.

Therefore, there were two main purposes of the study. The first purpose was to compare the DPSI scores between the RWDP and the NDP protocols and establish the relationship between these protocols. Understanding the differences and the relationships between two protocols may allow for a broader scope of knowledge and understanding in the area of dynamic postural stability. The second purpose is to compare shod and barefoot DPSI scores and establish the relationship between two footwear conditions. Understanding the effects of landing protocols and footwear conditions would allow for dynamic postural stability testing to be standardized and relatable to the current and future literature. It is hypothesized that both protocols and footwear conditions would result in significantly different DPSI scores (higher DPSI scores in the RWDP protocol and in the shod condition) while these protocols and conditions were highly correlated.

Methods

Subjects

An a priori analysis determined that a sample size of 25 would be sufficient for completion of data collection with a desired power of 80%. Healthy, physically active males and females between the ages of 18 and 35 were recruited for this study. Physically active was defined as engaging in 30 minutes of physical activity a minimum of three times a week. Participants had to be able to complete a jumping task. Interested persons were excluded from participation if they had sustained a lower extremity injury in the previous three months, a previous lower extremity injury which lead to 6 months or more of loss of function, a history of surgery to the dominant limb, head injury in the previous two months, or any injury that could impede or prevent their ability to complete a jumping task.

A total of 25 participants (13 males and 12 females) volunteered for this study (age: 22.1 ± 4.2 years, height: 178.3 ± 11.1 centimeters, weight: 75.6 ± 19.4 kilograms). The average Sports Activity Rating (Noyes, Barber, & Mooar, 1989) was 90.0 ± 8.3. Each participant exercised at least three times per week. The majority of participants wore standard athletic shoes (11 out of 25) or running shoes (10 out of 25) for testing while the 4 remaining participants wore minimalist footwear. None of the shoes had been worn for greater than 3 years (0.8 ± 0.7 years). The self-selected footwear condition was utilized in order to most accurately represent previous studies which used the NDP or RWDP.

Procedures

Participants reported to the lab for a single, one-hour testing session. Before any data collection, participants were provided a copy of an informed consent document approved by the University's Human Research Protection Office. All demographic data was collected first. This included participant's age, height with a wall-mounted stadiometer (Seca, Hanover, MD), and weight with an electronic scale (Cosmed USA Inc., Chicago, IL). Additionally, Sports Activity Rating Scale (Noyes et al., 1989) and shoe information (types: athletic shoes, running shoes, or minimalist shoes; and the duration of having the shoes) was collected.

A piezoelectric force plate (Kistler 9286A, Amherst, NY) was used to collect the ground reaction force (GRF) data to calculate the DPSI score. The force plate was embedded in a custom-made platform, which allowed the subject to take off from a surface level to the force plate during jump landing tasks. A sampling frequency of 1200 Hz was used for force plate measures during the dynamic task.

All participants were given time to practice each jumping task until they were comfortable and able to complete the task. Participants completed three practice trials for each condition. The order of jumping tasks as well as barefoot and shod conditions was randomized for each participant in order to minimize any potential confounding of a learning effect. Limb dominance for all tests was defined as the limb that the participant would use to maximally kick a soccer ball.

The RWDP protocol was previously described in detail (Ross & Guskiewicz, 2003; Wikstrom et al., 2005). In this protocol, the maximum vertical jump using a Vertec vertical jump device (Sports Imports, Columbus, OH) was measured first under the shod and barefoot conditions. Three trials of maximum jump height were completed and the highest jump was recorded. After determining the maximum jump height, participants started from 70cm behind the center of the force plate. The Vertec device was placed in line with the center of the force plate at a height of 50% of the participant's maximum vertical jump. The participant jumped off two feet and touched the overhead Vertec marker with the hand on the same side as their dominant leg. They then landed on the center of the force plate with only their dominant foot. Participants gained their balance as quickly as possible and placed their hands on their hips when balance was attained. They were instructed to maintain single leg stance as steady as possible for 5 seconds upon attaining balance. If the participants failed to touch the Vertec marker, to land on the center of the force plate, or to maintain their balance for 5 seconds, the trial was repeated. Three successful trials were collected for each condition, barefoot and shod, for a total of six collected trials using RWDP. The DPSI scores using the RWDP protocol have an excellent intersession reliability (ICC = 0.96) and low standard error of the measurement (SEM = 0.03) (Wikstrom et al., 2005).

The NDP protocol was previously described (Sell et al., 2012). Participants stood on two legs at a distance of 40% of their body height from the force plate, jumped toward the force plate, initiating enough height to clear a 30-cm hurdle, which was placed at the midpoint of the 40% distance. They then landed on the center of the force plate with only their dominant foot. Participants gained their balance as quickly as possible and placed their hands on their hips when balance was attained. They were instructed to stand as steady as possible for 5 seconds upon attaining balance. Jumps were recollected if any of the cancellation events listed for RWDP occurred with the exception of the touching of the Vertec marker. For NDP, if a participant did not fully clear the hurdle, the trial was recollected. Upper extremity movement was not restricted during the task. Three successful trials were gathered for each condition. The NDP has been shown to have a very good reliability and precision (ICC = 0.86, SEM = 0.01) (Sell et al., 2012).

Data Reduction

Demographic data was manually entered into a database on a personal computer by the principal investigator. For DPSI, data was reduced within Vicon Nexus Software and processed with a custom script in Matlab R2012a (The Mathworks, Natick, MA). The DPSI was calculated using GRF data in the x, y, and z directions collected by the force plate during a jump landing task. The DPSI is a composite score of the medial-lateral stability index (MLSI), anterior-posterior stability index (APSI), and vertical stability index (VSI) (Wikstrom et al., 2005). The MLSI and APSI were calculated by the mean square deviations of fluctuations around a zero point in the frontal (x) and sagittal (y) axes of the force plate, respectively. The VSI was calculated by assessing the fluctuations from the subject's bodyweight in the vertical (z) direction of the force plate. All stability indices were calculated using the first three seconds of GRF data following initial contact with the force plate. The average of three consecutive trials was used to calculate APSI, MLSI, VSI, and DPSI scores during each protocol and footwear condition.

Statistical Analyses

All variables were analyzed using SPSS (v23, SPSS Inc., Chicago, IL). Descriptive statistics (means and standard deviations) were calculated for all variables. All data was examined for normality using the Shapiro-Wilk test, and normally distributed data was analyzed using paired samples t-tests to compare DPSI scores between the RWDP and the NDP along with the differences between footwear. Data that was not normally distributed was analyzed using a Wilcoxon Signed Ranks tests to compare the scores. A Pearson correlation coefficient or Spearman correlation coefficient was used to determine if a correlation existed in the DPSI scores between the RWDP and the NDP, and also within protocol with different footwear. An alpha level of 0.05 was set *a priori* as a significance level for statistical analyses. Effect size (ES) and power of each comparison were also calculated using G*Power 3 statistical software (Franz Faul, Universitat Kiel, Germany).

Results

Descriptive statistics of the DPSI scores between two protocols (RWDP and NDP) and comparisons/correlations are shown in Table 1. In the shod condition, the NPD had significantly higher APSI (RWDP: 0.100 ± 0.008, NDP: 0.137 ± 0.010, p = 0.011, ES = 3.416, power = 1.000) and lower MLSI scores (RWDP: 0.033 ± 0.006, NDP: 0.028 ± 0.006, p < 0.001, ES = 0.550, power = 0.752). There was a significant correlation on the VSI score (r = 0.416, p = 0.039) between the protocols.

In the barefoot conditions, the NDP had significantly higher APSI (RWDP: 0.101 ± 0.010; NDP: 0.135 ± 0.010, p < 0.001, ES = 3.409, power = 1.000) and lower MLSI (RWDP: 0.031 ± 0.006, NDP: 0.026 ± 0.006, p < 0.001, ES = 0.805, power = 0.971) and VSI scores (RWDP: 0.319 ± 0.030, NDP: 0.299 ± 0.035, p = 0.003, ES = 0.667, power = 0.877). There were significant correlations on MLSI, VSI, and composite DPSI scores (r = 0.302 – 0.578, p = 0.003 – 0.016).

Descriptive statistics of the DPSI scores between footwear conditions (shod and barefoot) and comparisons/correlations are shown in Table 2. Within the RWDP protocol, there were no significant differences between the footwear conditions (p = 0.074 – 0.694, ES = 0.080 – 0.373, power = 0.067 – 0.433). Contrarily, all DPSI scores in the RWDP protocol between the footwear conditions were significantly correlated (r = 0.420 – 0.807, p = 0.001 – 0.037).

Within the NDP protocol, all of the DPSI scores in the shod condition were significantly higher when compared to the barefoot conditions (p = 0.001 - 0.039). There were significant correlations between the shod and barefoot conditions (r = 0.660 - 0.884, p < 0.001).

Table 1. Comparisons and Associations Between the Two Jump Protocols: Means (SD)

Variables	RWDP	NDP	T-tests p-value	Effect Size	Power	Correlation	Correlation p-value
DPSI Scores while Shod							
APSI Score	0.100 (0.008)	0.137 (0.010)	0.011	3.416	1.000	0.273	0.187
MLSI Score	0.033 (0.006)	0.028 (0.006)	<0.001	0.550	0.752	0.151	0.470
VSI Score	0.327 (0.035)	0.317 (0.031)	0.189	0.270	0.254	0.416	0.039
Composite Score	0.344 (0.033)	0.347 (0.030)	0.654	0.382	0.072	0.382	0.060
DPSI Scores while Barefoot							
APSI Score	0.101 (0.010)	0.135 (0.010)	<0.001	3.409	1.000	0.477	0.142
MLSI Score	0.031 (0.006)	0.026 (0.006)	<0.001	0.805	0.971	0.302	0.016

VSI Score*	0.319 (0.030)	0.299 (0.035)	0.003	0.667	0.877	0.578	0.003
Composite Score*	0.337 (0.027)	0.330 (0.033)	0.143	0.245	0.209	0.569	0.003

*Nonparametric Analyses. DPSI: Dynamic Postural Stability Index, RWDP: Ross/Wikstrom DPSI Protocol, NDP: Neuromuscular Research Laboratory DPSI Protocol, APSI: Anterior-Posterior Stability Index, MLSI: Medial-Lateral Posterior Stability Index, VSI: Vertical Stability Index.

Table 2. Comparisons and Associations Between Shod and Barefoot Conditions: Means (SD)

Variables	Shod	Barefoot	T-tests p-value	Effect Size	Power	Correlation	Correlation p-value
DPSI Scores within RWDP							
APSI Score	0.100 (0.008)	0.101 (0.010)	0.694	0.080	0.067	0.455	0.022
MLSI Score	0.033 (0.006)	0.031 (0.006)	0.345	0.192	0.152	0.420	0.037
VSI Score	0.327 (0.035)	0.319 (0.030)	0.074	0.373	0.433	0.807	<0.001
Composite Score	0.344 (0.033)	0.337 (0.027)	0.090	0.353	0.395	0.786	<0.001
DPSI Scores in NDP							
APSI Score	0.137 (0.010)	0.135 (0.010)	0.039	0.437	0.555	0.884	<0.001
MLSI Score	0.028 (0.006)	0.026 (0.006)	0.016	0.521	0.706	0.660	<0.001
VSI Score*	0.317 (0.031)	0.299 (0.035)	<0.001	0.968	0.995	0.847	<0.001
Composite Score*	0.347 (0.030)	0.330 (0.033)	<0.001	1.071	0.999	0.870	<0.001

*Nonparametric Analyses. DPSI: Dynamic Postural Stability Index, RWDP: Ross/Wikstrom DPSI Protocol, NDP: Neuromuscular Research Laboratory DPSI Protocol, APSI: Anterior-Posterior Stability Index, MLSI: Medial-Lateral Posterior Stability Index, VSI: Vertical Stability Index.

Discussion

The purpose of this study was to compare and correlate the DPSI scores between two different protocols (RWDP and NDP) and between footwear conditions (shod and barefoot). For the first aim, which examined the effect of protocols on DPSI scores, the hypotheses were mostly rejected as there were no differences in the composite DPSI scores between the protocols in the shod ($p = 0.654$) and barefoot condition (p = 0.143) while there was a significant correlation between the protocols in the barefoot conditions (r = 0.569, p = 0.003). For the second aim, which examined the effect of footwear on DPSI scores, the hypotheses were partially supported as the composite DPSI scores between the footwear conditions were significantly different (p < 0.001) during the barefoot condition but not in the shod condition (p = 0.090). The DPSI scores between the footwear conditions were significantly correlated (r = 0.420 – 0.884, p = 0.001 – 0.037) for both within the RWDP and the NDP protocol, supporting the hypotheses.

The shod DPSI values during the NPD protocol in the current study are similar to the shod DPSI values from previous studies with the NPD protocol (Pederson, 2011; Whitehead et al., 2014), supporting that procedures and calculations were properly executed. Previous studies on the DPSI values under the RWPD protocol had large variability (Liu et al., 2013; Wikstrom et al., 2010), making it difficult to compare with the current DPSI scores in the RWPD protocol. In the current study, the composite DPSI values during the RWPD were 0.344 and 0.337 in the shod and barefoot conditions, respectively. The current DPSI values during the RWPD protocol would fall somewhere between the values reported by the previous studies.

There were two common protocols to assess the DPSI in the sports medicine and rehabilitation literature (RWDP and NDP). To our knowledge, there have been no studies comparing the DPSI scores between different protocols. The current investigation aimed to see if small differences in these protocols such as jump distance/height, visual attention, and arm movements could result in significant differences in the DPSI scores. Previous studies have indicated significant influence of jump distance/height, visual attention, and arm movements in the literature. For example, increased jump distance would lead to increased landing demands, which would increase the vertical and anterior/posterior GRF (Heebner, 2015). As these GRF values are part of the DPSI calculation, it is anticipated that an increase in GRF would lead to increased DPSI scores. The average normalized jump distance for the NDP was 33 cm longer than the standard jump distance in the RWDP. Therefore, it was speculated that the DPSI scores were higher during the NPD. This contention was supported by the current results that demonstrated significantly higher APSI scores in the NDP when compared to the RWDP protocol regardless of the footwear conditions.

Higher GRF/APSI scores due to longer jump distance in the NDP protocol might have been cancelled out by other factors (visual attention and arm movements), resulting in no significant differences in the composite DPSI scores. In the RWDP, because participants must touch an overhead marker, participant’s attention was focused on the marker more than the landing site in the RWDP. This was different in the NDP where participants were able to maintain visual attention on the landing site for the majority of the jump. The role of vision during dynamic tasks and balance has been investigated in the past. It has been demonstrated that proprioception and vestibular feedback cannot fully compensate for the lack of visual feedback during a landing activity (Santello et al., 2001). A lack of visual feedback greatly diminishes an individual’s ability to balance, and as much as two times higher balance scores in the eyes closed condition were reported (Sell et al., 2012). Although the RWDP does not require participants to keep their eyes closed, the protocol likely causes attention to be away from the landing zone with focus being on the vertec. This is seen in larger MLSI and VSI scores in the RWDP when compared to the MLSI and VSI values in the NDP protocols. The mechanics of the NDP also required a more horizontal jump over the hurdle compared to a more vertical jump to touch the overhead marker in the RWDP. The NDP mechanics may have lead to an increased APSI versus the RWDP mechanics may have lead to an increased VSI.

Another difference that might have influenced the results is different arm movements between protocols. In the RWDP, arm movements were restricted due to the requirement of touching the overhead marker with the hand on the same side as the dominant foot. The NDP had no arm movement requirements or restrictions. Previously, arm movements in vertical jumps increase the maximum takeoff force and decrease the landing impact (Shetty & Etnyre, 1989). There are limited studies investigating the effect of arm movements on the DPSI scores during single leg jump landing tasks. However, the restrictions on arm movements in the RWDP would increase DPSI scores due to limiting the ability of the arms to decrease the landing impact as compared to the free arm movement in the NDP. In short, one constraint (longer jump distance in NDP) is matched by two constraints (less visual attention and restricted arm movements in the RWDP), resulting in no significant differences in the composite DPSI scores between two protocols.

There were mixed results for correlations between the two protocols (not significant ($p = 0.060$) in the shod condition; significant ($p = 0.003$) in the barefoot condition). It was believed that the overall dynamic postural stability of each participant was a constant and the change seen in DPSI scores would be solely due to the differences in the protocols. With subjects as their own controls, the DPSI scores were expected to vary between protocols but be significantly correlated due to the constant nature of their dynamic postural stability. The current result in the barefoot condition supports this contention. Contrarily, although there was a trend ($p = 0.060$), there was no significant correlation between the RWDP and NDP in the shod condition. Because the shod composite DPSI score between the protocols had very low statistical power, more subjects might be needed.

For the second aim, the current study found that there was a significant difference between the shod and barefoot conditions within the NDP ($p = 0.001 – 0.039$). It was also found that there was a significant positive correlation between the shod and barefoot condition within the NDP ($r = 0.870$; $p < 0.001$). These findings are in accordance with a previous study investigating the DPSI scores, which reported a significant difference in DPSI scores between standard athletic shoes, military boots, and minimalist footwear (minimalist footwear being the lower DPSI scores) (Whitehead et al., 2014). A potential reasons that explain the significant differences between the shod and barefoot conditions is that subjects would alter landing technique to increase forefoot strike in the barefoot condition (Lieberman et al., 2010). The authors (Lieberman et al., 2010) reported forefoot landing lead to decreased GRFs, which are directly associated with DPSI scores. The current findings support this explanation as the barefoot condition had lower VSI scores, specifically in the NDP.

Interestingly, there were no significant differences in the DPSI scores between the footwear conditions during the RWDP protocol ($p = 0.074 – 0.694$). The current result was contrary to the previous study that has reported significant differences in the DPSI scores between the barefoot, athletic shoes, and minimalist conditions utilizing a jump-landing protocol with a standard jump distance (Rose et al., 2011). In their study, the barefoot condition resulted in the lowest DPSI scores that is similar to the study by

Whitehead and colleagues (Whitehead et al., 2014). When combining the results (effects of protocols and footwear conditions) of the current investigation, there is evidence that the two protocols were not significantly different; however, the NDP protocol was more sensitive than the RWDP to detect small differences caused by footwear conditions.

In the current study, there were significant correlations between the shod and barefoot conditions regardless of the protocols, supporting the hypotheses. When looking at the correlation values closely, the correlations between the footwear conditions within the NDP protocol had higher correlation values ($r = 0.660 – 0.884$) than the correlations within the RWDP protocol ($r = 0.420 – 0.807$).

Limitations of the current study should be recognized. One limitation was that participants used self-selected footwear. This decision was made in an attempt to best replicate previous studies using the DPSI which did not standardize footwear. Participants varied in self-selected footwear. This difference, though reflective of the previous literature, may significantly affect the DPSI scores. Second, females have significantly higher DPSI values than males (Wikstrom, Tillman, Kline, & Borsa, 2006). This effect could potentially influence the data but was accounted for as best as possible by recruiting and testing an even number of males and females. Also, due to the individuals serving as their own controls, the influence of gender differences in the current study would likely be small. Based on the current DPSI data in an athletic and young population of males and females, no significant differences were found in DPSI scores in either protocol or footwear condition. Third, a previous study has shown that balance decreases as age increases (Bohannon, Larkin, Cook, Gear, & Singer, 1984). No studies have investigated the effect of aging on either the NDP or the RWDP. If the significant change in balance with aging is also seen in either protocol, it could influence the data. The ages of the participants in this study was young and comparable to other studies which also utilize these protocols (Sell et al., 2012; Wikstrom et al., 2005). Therefore, the results in the current study are only generalizable to the similar demographics.

Conclusions

Varying footwear results in significantly different DPSI scores more so than varying protocols. Particularly, the DPSI scores between the shod and barefoot conditions during the NDP protocol were significantly different. When utilizing the existing literature or conducting new studies, if footwear was not controlled, ambiguous results may have been collected and analyzed, leading to inaccurate conclusions. Practically and clinically speaking, the DPSI could be assessed in the barefoot condition when used to examine the effects of surgery and rehabilitation. The barefoot condition provides a true control as all individuals completing the task can potentially complete it barefoot. Additionally, the NDP protocol might be advantageous over the RWDP protocol due to its sensitivity to detect small changes and the ease of testing (requires a 30cm hurdle rather than Vertec).

Conflict of Interest: None declared.

Ethical Approval: This research project was reviewed and approved by the University Human Research Protection Office. Prior to participation, informed consent was provided to subjects, and their consent was obtained.

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References

Bohannon, R. W., Larkin, P. A., Cook, A. C., Gear, J., & Singer, J. (1984). Decrease in timed balance test scores with aging. *Phys Ther, 64*(7), 1067-1070.

Chaudhry, H., Findley, T., Quigley, K. S., Bukiet, B., Ji, Z., Sims, T., & Maney, M. (2004). Measures of postural stability. *J Rehabil Res Dev, 41*(5), 713-720.

Goldie, P. A., Bach, T. M., & Evans, O. M. (1989). Force platform measures for evaluating postural control: reliability and validity. *Arch Phys Med Rehabil, 70*(7), 510-517.

Heebner, N. R. (2015). *The effect of jump distance on biomechanical risk factors for ACL injury during landing and their relationship with sensorimotor characteristics at the knee.* (Doctoral Dissertation), University of Pittsburgh.

Kerr, B., Condon, S. M., & McDonald, L. A. (1985). Cognitive spatial processing and the regulation of posture. *J Exp Psychol Hum Percept Perform, 11*(5), 617-622.

Lieberman, D. E., Venkadesan, M., Werbel, W. A., Daoud, A. I., D'Andrea, S., Davis, I. S., . . . Pitsiladis, Y. (2010). Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature, 463*(7280), 531-535.

Liu, K., Glutting, J., Wikstrom, E., Gustavsen, G., Royer, T., & Kaminski, T. W. (2013). Examining the diagnostic accuracy of dynamic postural stability measures in differentiating among ankle instability status. *Clin Biomech (Bristol, Avon), 28*(2), 211-217.

Noyes, F. R., Barber, S. D., & Mooar, L. A. (1989). A rationale for assessing sports activity levels and limitations in knee disorders. *Clin Orthop*(246), 238-249.

Pederson, J. (2011). *Investigating the relationship between FAI questionnaires and measures of static and dynamic postural stability.* (Master's Thesis), University of Pittsburgh.

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

Riemann, B. L., Guskiewicz, K. M., & Shields, E. W. (1999). Relationship between clinical and forceplate measures of postural stability. *J Sport Rehab, 8*, 71-82.

Rose, W., Bowser, B., McGrath, R., Salerno, J., Wallace, J., & Davis, I. (2011). *Effect of footwear on balance.* Paper presented at the American Society of Biomechanics Annual Meeting, Long Beach, CA.

Ross, S. E., & Guskiewicz, K. M. (2003). Time to stabilization: A method for analyzing dynamic postural stability. *Athl Ther Today, 8*(3), 37-39.

Santello, M., McDonagh, M. J., & Challis, J. H. (2001). Visual and non-visual control of landing movements in humans. *J Physiol, 537*(Pt 1), 313-327.

Sell, T. C., House, A. J., Abt, J. P., Huang, H. C., & Lephart, S. M. (2012). An examination, correlation, and comparison of static and dynamic measures of postural stability in healthy, physically active adults. *Phys Ther Sport, 13*(2), 80-86.

Shetty, A. B., & Etnyre, B. R. (1989). Contribution of arm movement to the force components of a maximum vertical jump. *J Orthop Sports Phys Ther*, *11*(5), 198-201.

Whitehead, P. N., Sell, T. C., Lovalekar, M., Darnell, M. E., Heebner, N. R., Abt, J. P., & Lephart, S. M. (2014). *Better dynamic postural stability while wearing minimalist footwear in physically-active male adults.* Paper presented at the Mid-Atlantic Regional Chapter of the American College of Sports Medicine Annual Scientific Meeting, Harrisburg, PA.

Wikstrom, E. A., Tillman, M. D., Chmielewski, T. L., Cauraugh, J. H., Naugle, K. E., & Borsa, P. A. (2010). Dynamic postural control but not mechanical stability differs among those with and without chronic ankle instability. *Scand J Med Sci Sports, 20*(1), e137-144.

Wikstrom, E. A., Tillman, M. D., Kline, K. J., & Borsa, P. A. (2006). Gender and limb differences in dynamic postural stability during landing. *Clin J Sport Med, 16*(4), 311-315.

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. *J Athl Train, 40*(4), 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. *Am J Sports Med, 33*(3), 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. *Scand J Med Sci Sports, 15*(5), 336-345.