COMPARISON AND CORRELATION OF DYNAMIC POSTURAL STABILITY INDICES OBTAINED DURING DIFFERENT DYNAMIC LANDING TASKS AND FOOTWEAR CONDITIONS

by

Joseph Lewis Schmitz

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This thesis was presented

by

Joseph Lewis Schmitz

It was defended on

May 26, 2017

and approved by

Jonathan S. Akins, PhD, Assistant Professor, Department of Biomedical Engineering, Widener University

Matthew Darnell, PhD, RD, CSSD, SCCC, Assistant Professor, Department of Sports Medicine and Nutrition

Mita Lovalekar, MBBS, PhD, MPH, Assistant Professor, Department of Sports Medicine and Nutrition

Paul Whitehead, MS, CSCS, Doctoral Student, Department of Sports Medicine and Nutrition

Thesis Co-Director: Takashi Nagai, PhD, ATC, CSCS, Assistant Professor, Department of Sports Medicine and Nutrition

Thesis Co-Director: Kevin Conley, PhD, ATC, Associate Professor, Department of Sports Medicine and Nutrition

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Joseph L. Schmitz

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Introduction: Dynamic postural stability is a commonly studied risk factor for lower-extremity injury. Single leg jump-landings (SLJL) and the dynamic postural stability index (DPSI) are widely used methods for testing and calculating dynamic postural stability. Two different SLJL protocols are often used to calculate DPSI scores throughout the literature: one is based on normalized jump distance (NDP) and the other is based on normalized jump height (RWDP), with or without shoes. Given the prevalence of these protocols, it is important to compare DPSI scores during the two different SLJL measures while examining the effect of footwear. **Methods:** Subjects (n=25) completed the two SLJL protocols shod and barefoot. Both protocols required subjects to jump-off two feet and land with their dominant foot on a force-plate. Based on normality, paired t-tests or Wilcoxon signed-rank tests and Pearson or Spearman correlation coefficient were used to compare and measure the relationship between the two protocols under two footwear conditions ($p<0.05$). **Results:** The NDP and RWDP were not significantly different from each other in either footwear condition ($p=0.233$; 0.654). The two protocols were significantly correlated under the barefoot condition ($r=0.565$; $p=0.003$), but not under the shod condition ($r=0.382$, $p=0.060$). NDP scores under the shod and barefoot conditions were significantly different ($p<0.001$) but correlated ($r=0.870$, $p<0.001$). RWDP scores under the shod and barefoot conditions were not significantly different ($p=0.090$) and correlated ($r=0.786$, $p<0.001$). **Conclusion:** Different protocols and footwear conditions may impact DPSI scores. Therefore, a standardized protocol and footwear condition should be established for future studies.

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PREFACE

I would like to thank the members of my committee for supporting me throughout this process. I would specifically like to thank Dr. Takashi Nagai for pushing me to pursue the Bachelor of Philosophy degree from the beginning. I would also like to specifically thank Dr. Paul Whitehead for his continuous support from white paper to defense. I would also like to thank all of the students, faculty, and staff at the Neuromuscular Research Laboratory for their encouragement and support.

1.0 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.[1] Postural stability has been found to be influenced by three main systems: visual, vestibular, and somatosensory.[2, 3] 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.[4] Dynamic postural stability is defined as an individual's ability to maintain balance while transitioning from a dynamic to a static state.[5] 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.[6] 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.[1, 7-9] 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.

The DPSI is a quantitative measure that scores an individual for dynamic postural stability through a single leg jump landing task which can be used to identify individuals at risk for injury. Both dynamic and static postural stability deficits have been associated with risk for injury.[8, 10-13]

Dynamic postural stability testing using a single leg jump landing mimics athletic maneuvers and challenges participants in order to reveal dynamic postural stability deficits.

Many tests are used in the literature to measure balance and postural stability such as the Star Excursion Balance Test,[14] the Biodex Stability System,[15] and the NeuroCom Sensory Organization Test.[16] Tests such as these are often seen in clinical practice, but they do not measure the dynamic stability of a person like a single leg jump landing task does. Tests that utilize the single leg jump landing are designed to mimic realistic movements and tasks. The protocols require a participant to jump off two feet and land on one foot. The participant then gains balance on one foot and maintains balance for five seconds. This jumping task is more dynamic and similar to the tasks a participant might encounter in real life.

There are two common single leg jump landing protocols that are quantified with DPSI: the Ross/Wikstrom DPSI Protocol (RWDP)[6, 7] and the Neuromuscular Research Laboratory DPSI Protocol (NDP)[1]. 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.[17-19] 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 will compare 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.[20, 21] Most recently, a study has revealed that participants have significantly different DPSI scores when they were wearing three different footwear: athletic shoes, military boots, and minimalist footwear during the NDP.[21] 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. Therefore, this study will compare the DPSI scores between shod and barefoot conditions to establish the relationship between two conditions.

1.1 POSTURAL STABILITY AND BALANCE

Postural stability and balance are nearly synonymous terms. As previously defined, postural stability plays a large role in the life of a human. Balance is defined as the dynamics of body posture to prevent falling.[22] Postural stability keeps humans on their feet and allows for many movements and activities. Postural stability is mainly influenced by three systems: visual, somatosensory, and vestibular.[2, 3] These systems work together to select and carry out appropriate and coordinated musculoskeletal responses in order to maintain stability. Poor postural stability has been reported to be associated with many injuries including ACL injury, ankle sprain, chronic ankle injury, and concussion.[8, 12, 13, 23] Postural stability is commonly divided into two categories: static postural stability and dynamic postural stability.

1.2 STATIC POSTURAL STABILITY

Static postural stability is influenced by all three systems (visual, somatosensory, and vestibular) of postural stability.[7] These systems develop in the early years of life and decline at an older age.[24, 25] Static postural stability is often tested for using a double or single leg stance where postural sway is measured. Postural sway can be defined as changes in the center of mass.[26]

1.2.1 Static Postural Stability as a Risk Factor for Injury

Static postural stability has not been unanimously identified as a risk factor for injury. Multiple studies have found associations between static postural stability and injury.[10, 11] Other studies have found no association between static postural stability and injury.[27, 28] Due to conflicting results, more research must be done to determine if static postural stability is a risk factor for injury.

1.3 DYNAMIC POSTURAL STABILITY

Dynamic postural stability, like static postural stability, is influenced by the three systems of postural stability and balance.[7] It has been identified as a more challenging and realistic task when compared to static postural stability assessments.[1] The dynamic movements completed in the dynamic postural stability tests replicate the actions of an athlete more accurately which allows for detection of possible risk factors for injury during competition.[1]

Dynamic postural stability is mainly studied using the RWDP and the NDP. These tests are used to quantify a DPSI score through dynamic movements and balance, which affect ground reaction forces. A lower DPSI score, when compared to group means, is associated with better dynamic postural stability, and higher DPSI scores are associated with worse dynamic postural stability.[1] Because many studies have utilized the RWDP or the NDP to assess the DPSI scores, it is important to understand the differences between the RWDP and the NDP protocols and identify a correlation between the protocols. With a correlation, it is possible to compare data across studies utilizing different protocols.

1.3.1 Dynamic Postural Stability as a Risk Factor for Injury

Both the RWDP and the NDP protocols have been shown to be reliable (Intraclass Correlation Coefficient (ICC) = 0.96 and 0.86, respectively).[1, 7] Additionally, those protocols have shown to be sensitive enough to differentiate individuals with and without musculoskeletal conditions or a concussion.[8, 13, 23] A prospective study by Willems et al.[8] reported that deficits in balance are associated with risk for injury. It has also been seen that DPSI can discriminate between healthy individuals and individuals with chronic ankle instability.[13] Additionally, it has been reported that individuals who have recently suffered a concussion have worse dynamic postural stability.[23] Dynamic postural stability testing is a proven tool for identifying individuals at risk for injury. By using this testing, it is possible to identify individuals at risk for injury and apply an intervention in an attempt to avoid injury all together. With varying protocols, it is difficult to compile relatable data and distinguish the risk of injury due to deficits in dynamic postural stability.

1.3.2 The Effect of Dynamic Postural Stability Protocols

When the RWDP was modified by Sell et al.,[1] no justifications were given for the changes made to the single leg jump landing protocol. It was mentioned that a more mobile set up was required for remote testing and that the hurdle jump would lead to increased posterior ground reaction forces (GRF). No relationship between protocols was determined. When the results from two separate studies are compared, the RWDP and the NDP are seen to produce noticeably different DPSI scores.[12, 29] This difference may be due to the variations within each protocol. The most important differences between protocols are jump height, jump distance, arm mechanics, and attention. The RWDP uses a normalized jump height and a standard jump distance for each participant.[6, 7] The RWDP also requires the participant to touch a vertical jump marker with one hand in the air. The NDP uses a normalized jump distance and a standard jump height for all participants.[1] The NDP requires the participant to focus on clearing a 30-cm hurdle placed on the floor. The participants in both protocols jump off two feet and land on one foot. The landing plate is a force plate that is used to capture the GRFs incurred upon landing and during stabilization.

It has been shown that increased jump distance increases vertical and anterior-posterior GRFs.[18] It has also reported that arm movements and attention can effect landing mechanics and balance.[17, 19, 30, 31] These differences may significantly effect DPSI scores between protocols.

1.3.3 The Effect of Footwear during Dynamic Postural Stability Testing

As previously mentioned, footwear has a significant effect on DPSI scores.[20, 21] In neither of the protocols mentioned above has there been a recommendation on appropriate footwear use. Like a standardized protocol, standardized footwear is required to allow for comparable data across the literature. If all dynamic postural stability testing were to be completed in a standardized footwear, it would ensure no effect due to the footwear. However, as previously stated, it is nearly impossible to use the same standardized footwear for every dynamic postural stability study. The simplest way to eliminate the effect of footwear is to do all DPSI testing barefoot. Historically, balance tests have recommended barefoot testing.[14, 16] This recommendation should also be used in testing using the DPSI.

1.4 DEFINITION OF THE PROBLEM

Multiple protocols are currently being used in studies throughout the literature to test for dynamic postural stability. These protocols vary in their jumping tasks and their methodologies. These variations in protocols lead to significantly different DPSI scores.[12, 29] With significantly different DPSI scores across protocols, it makes the results from studies utilizing varying protocols difficult to compare. Without the ability to compare data across the literature, the understanding of dynamic postural stability testing is only limited to studies with the same protocol.

There is also no footwear recommendation within any DPSI protocols. Studies have shown that the use of varying footwear within participants results in significantly different DPSI scores.[20, 21] If footwear has an effect on DPSI scores, it can be argued that all DPSI testing must be completed in a standardized footwear in order to maintain comparability. Eliminating footwear all together would allow for a standardized barefoot condition in all dynamic postural stability testing and lead to more comparable data.

1.5 PURPOSE

The first purpose of this study is to compare the DPSI scores between the RWDP and the NDP protocols and establish the relationship between these protocols in a young, athletic population. 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. If data from the protocols is not comparable, the argument can be made for a consistent protocol to be used for all dynamic postural stability testing. If data does show comparability, it may still be wise to unify a protocol for all dynamic postural stability testing using a single leg jump landing and being quantified with the DPSI.

The second purpose of this study is to compare shod and barefoot DPSI scores and to establish the relationship between two footwear conditions in a young, athletic population. Similar to the issue of seeing results of different protocols in the literature, varying footwear may have an effect on DPSI scores and make data collected using inconsistent footwear unable to be compared. If an effect is observed, a footwear recommendation can be made for all dynamic postural stability testing in order to maintain comparability.

1.6 SPECIFIC AIMS AND HYPOTHESES

<u>Specific Aim 1</u>: To compare the shod DPSI scores between the RWDP and the NDP protocols and establish the relationship between these protocols.

<u>Hypothesis 1a</u>: There will be a significant difference ($p < 0.05$) in the shod DPSI scores between the RWDP and the NDP. Due to the decreased attentional demands

and arm mechanics, the shod NDP will have significantly lower DPSI values than the shod RWDP.

Hypothesis 1b: Due to the constant nature of dynamic postural stability, there will be significantly positive correlation ($p < 0.05$) in shod DPSI scores between the RWDP and the NDP.

Specific Aim 2: To compare the barefoot DPSI scores between the RWDP and the NDP protocols and establish the relationship between these protocols.

Hypothesis 2a: There will be a significant difference ($p < 0.05$) in the barefoot DPSI scores between the RWDP and the NDP. Due to the decreased attentional demands and arm mechanics, the barefoot NDP will have significantly lower DPSI values than the barefoot RWDP.

Hypothesis 2b: Due to the constant nature of dynamic postural stability, there will be significantly positive correlation ($p < 0.05$) in barefoot DPSI scores between the RWDP and the NDP.

Specific Aim 3: To compare the shod and barefoot DPSI scores using the RWDP protocol and establish the relationship on the two footwear conditions.

Hypothesis 3a: Based off previous research, there will be a significant difference ($p < 0.05$) between shod and barefoot DPSI scores when using the RWDP. Due to increased proprioceptive feedback, barefoot scores will be significantly lower than shod scores.

Hypothesis 3b: Due to the constant nature of dynamic postural stability, there will be a significantly positive correlation ($p < 0.05$) between shod and barefoot DPSI scores when using the RWDP.

Specific Aim 4: To compare the shod and barefoot DPSI scores using the NDP protocol and establish the relationship on the footwear two conditions.

Hypothesis 4a: Based off previous research, there will be a significant difference ($p < 0.05$) between shod and barefoot DPSI scores when using the NDP. Due to increased proprioceptive feedback, barefoot scores will be significantly lower than shod scores.

Hypothesis 4b: Due to the constant nature of dynamic postural stability, there will be a significantly positive correlation ($p < 0.05$) between shod and barefoot DPSI scores when using the NDP.

1.7 STUDY SIGNIFICANCE

Dynamic postural stability is often assessed using the DPSI. Poor DPSI scores are associated with risk for injury.[6, 8, 13, 23, 32] Two different protocols (the RWDP and the NDP) are often seen throughout the literature that are used to study dynamic postural stability. It is believed that these two protocols yield significantly different results due to the differences in jump height, jump distance, arm mechanics, and attention. If the results are significantly different, they cannot be compared and compiled in order to further the understanding and significance of dynamic postural stability. It is also important to determine the effect of footwear on the DPSI score. It is believed that varying footwear can result in significantly different DPSI scores.[21] This study will use subject self-selected athletic footwear as most previous studies have done along with a barefoot condition. These findings will allow for DPSI testing in a young, athletic population to be more relatable throughout the literature.

2.0 REVIEW OF THE LITERATURE

Balance and postural stability are widely studied topics throughout scientific literature. Both balance and postural stability effect the lives of individuals from start to finish. Children learn to balance as they begin to sit up and walk while the elderly slowly lose their postural stability as they continue to age.[33] Postural stability is influenced by multiple internal systems of the body and can be broken down into more specific categories including static postural stability and dynamic postural stability.[22] Both static and dynamic postural stability have been identified as potential risk factors for injury. Dynamic postural stability specifically has been identified as a risk factor for multiple types of injury including ACL injury, ankle sprains, and chronic ankle instability.[8, 12, 32] Dynamic postural stability has been tested using multiple methods including the Biodex Stability System, NeuroCom Sensory Organization Test, the Star Excursion Balance Test, and the DPSI. The DPSI was originally modified by Wikstrom et al.[7] from the time to stabilization test created by Ross et al.[6] Since the DPSI was created, it has been modified further by Sell et al.[1] at the University of Pittsburgh Neuromuscular Research Laboratory.

The use of DPSI testing has become a common practice throughout literature. Testing of this nature has the ability to reveal and quantify postural stability deficits in patients and athletes.[7] The effect of gender on DPSI has also been tested, and it was found that females had a significantly higher (worse) DPSI score than males.[34] Though DPSI has proven to be useful in comparing injured versus uninjured and differences between genders, there is difficulty comparing data across studies due to the varying protocols. With different jump landing protocols, the results from separate studies cannot be confidently compared until an investigation has determined the relationship between results of the two protocols. Footwear has also been found to have a significant effect on DPSI scores.[21] It is important to understand the effect that footwear has on DPSI and to find a relationship between the varying DPSI protocols.

2.1 POSTURAL STABILITY AND BALANCE

Balance and postural stability are closely related concepts. This system is controlled by sensory and motor systems which contribute to stabilization.[35] Balance and posture have been found to be influenced by three major sensory systems, seen in figure 1.[22] First, vision allows for the identification of obstacles and the planning of movements. Second, the vestibular system is able to sense both linear and angular accelerations. The last system is the somatosensory/proprioception system which allows for the conscious perception of the bodies position and movement.[22, 36] These systems send afferent information to the central nervous system which sends efferent information back in order to keep the body upright and stable. Attention, defined as the information processing capacity of an individual, could result in differences in DPSI scores between protocols.[17] A study by Kerr et al.[17] used 24 college students and a blindfolded postural stability task. The participants were required to balance in a tandem Romberg position while completing the Brooks spatial memory task and a non-spatial memory task which required participants to remember similar sentences. The Books spatial memory task involved the participants placing numbers in an imaginary grid and being asked to recall the position of the numbers in the grid. The results showed an increase in spatial errors but no change in non-spatial errors. The investigators concluded that postural control is attentionally demanding in young adults. They also concluded that different cognitive tasks have different effects on postural control. No differences in postural sway were seen for any cognitive task.

Postural stability is often broken into two common categories: static postural stability and dynamic postural stability. A study by Sell et al.[1] revealed that there is a lack of correlation between static and dynamic measures of postural stability. Both categories of postural stability have been studied using multiple tests and protocols.

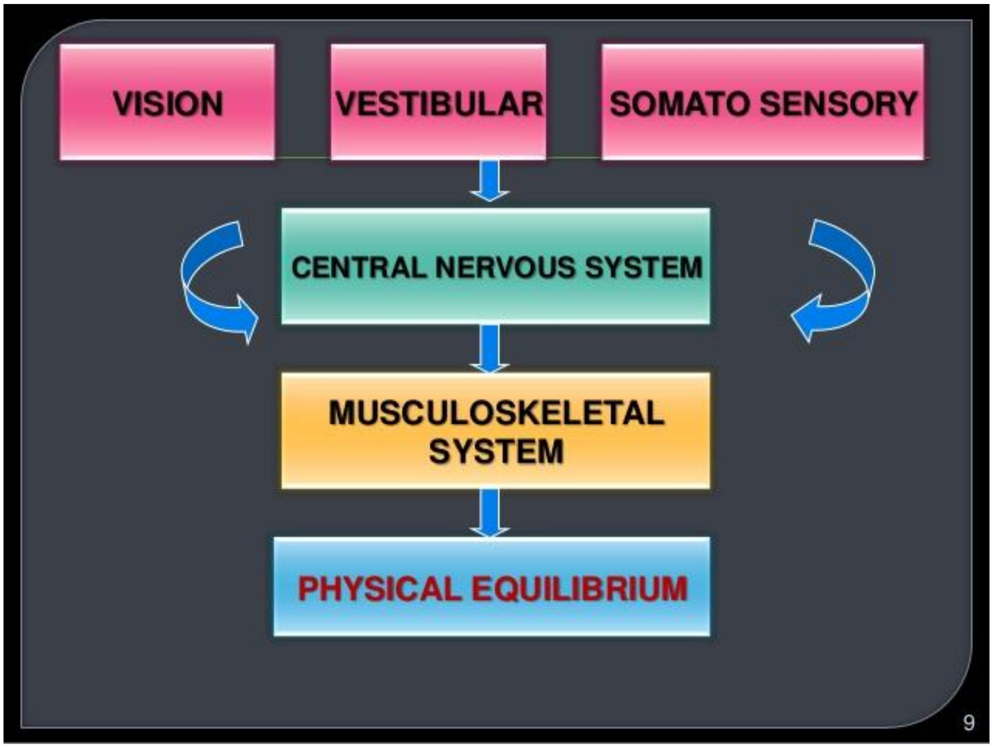

Figure 1. Systems involved in postural stability and balance[37]

2.2 STATIC POSTURAL STABILITY

Static postural stability can be defined as the ability to maintain balance in quiet stance (no movement).[26] Static postural stability develops at a young age and is considered to be "adult-like" around the age of 7-8.[24] At this point, the three systems involved in balance (vision, vestibular, and somatosensory) are considered fully functional. Afferent feedback from the body to the central nervous system is more abundant and sensitive. This results in a change from large and fast balance corrections to small and frequent corrections.[25] Static postural stability is often measured using a double or single leg static balance test.[1, 26, 38] In these tests, participants are asked to maintain a stable position and limit movement as much as possible. Stability ratings are based on the amount of postural sway and changes in center of mass of the participant.[26, 38] Within these tests, participants are often asked to balance with their eyes closed. This eliminates vision, one of the three systems involved in balance, which allows for a closer look at the influence of the vestibular and somatosensory systems. As previously stated, there has been shown to be a lack of correlation between static and dynamic postural stability.[1] This being said, static postural stability has been identified as a risk factor for injury.

2.2.1 Static Postural Stability as a Risk Factor for Injury

Static postural stability and its association with injury has been disputed throughout the literature. A prospective study by Hopper et al.[27] found no significant difference in static balance between injured and uninjured netball players (injured = 12.84 ± 10.19, uninjured = 12.19 ± 10.20). The study consisted of netball players (n=72) competing at the same Centre over a season of play. The participants were asked to complete a single leg balance for 30 seconds in the barefoot condition. Another study by Beynnon et al.[28] report that static postural stability is unrelated to injury. This prospective study consisted of 118 male and female Division I collegiate athletes who played soccer, lacrosse, or field hockey. A NeuroTest system, with a non-sway force plate was utilized to measure postural stability with shoes. Neither women nor men had significantly different postural stability measurements between injured and uninjured (women: injured = 3.4 ± 0.32, uninjured =

3.4 ± 0.33, p = 0.65; men: injured = 3.6 ± 0.55, uninjured = 3.0 ± 0.24, p = 0.21). No footwear recommendation was used or made in this study.

Other studies have shown that static postural stability is a risk factor for injury. McGuine et al.[10] found that increased postural sway is a predictor for ankle sprain. This study used male and females high school basketball players (n=210). Static postural stability was tested using a single leg balance test with shoes where participants stood on a single leg for ten seconds. Participants would complete this task three times with their eyes open and three times with their eyes closed. The study found that athletes with worse/higher scores sustained significantly more ankle sprains than athletes with better/lower scores (2.01 ± 0.32, 1.74 ± 0.31, p = 0.001). Again, no footwear recommendation was used or made in this study. Another study by Soderman et al.[11] reported that athletes with diminished balance were at an increased risk for leg injury. The study used female soccer players (n = 221) and a postural sway test similar to that of the previously mentioned study by McGuine et al.[10] No footwear recommendation was used or made in this study. It is unclear whether static postural stability is a risk factor for injury according to the conflicting data presented above.

2.3 DYNAMIC POSTURAL STABILITY

Dynamic postural stability can be defined as the ability to transfer the vertical projection of the center of gravity around the supporting base.[1, 5] This type of stability depends on proprioceptive feedback and preprogrammed muscle patterns, along with both reflexive and voluntary muscle responses.[39] Dynamic postural stability has begun to be studied more often than static postural stability due to dynamic testing being more functional and applicable to the athletic population.[1] There are multiple methods that are used to test for dynamic postural stability.

The first dynamic postural stability testing method is the Biodex Stability System (Biodex Inc.), which was used by Salavati et al.[40] to investigate the effect of fatigue on postural stability. The system has a circular moveable platform linked to a computer that allows it to perform objective stability indices measurements. Participants were asked to keep the unstable platform as level as possible for 20 seconds. The platform displacement was used to calculate their overall stability index, anterior-posterior stability index, and medial-lateral stability index. This assessment is limited because that it evaluates dynamic postural stability in an unrealistic way. Riemann et al.[4] reported that this type of postural stability testing might be too easy and not produce postural stability deficits in participants. Sell et al.[1] also found that DPSI testing was more difficult or challenging. The Biodex Stability System recommends testing to be completed with participants in non-skid footwear.[15]

Figure 2. Biodex Stability System[41]

Another test that is used to evaluate stability is the NeuroCom International (Clackamas, Oregon) dynamic posturography system Sensory Organization Test (SOT). The system allows for the three systems of balance to be evaluated individually. The machine has a platform that can be static or dynamic and a surrounding visual wall that also can be static or dynamic. Using variations of these features being static or dynamic with the combination of eyes open or eyes closed, all aspects of balance can be challenged. The main outcome of this testing is called the "equilibrium score."[2] The system recommends testing participants in non-slip socks in order to achieve standardized input from the somatosensory system cues. They also recommend this in order to compare the normative data. The company does allow for shod testing if deemed medically necessary but any re-testing must be completed in the same footwear. With shod testing, the data cannot be compared to the normative data set.[16] This system, however, does not provide a dynamic test like the single leg jump landing that mimics an athletic maneuver.

Figure 3. NeuroCom[42]

Another test that is used to evaluate stability is the Star Excursion Balance Test (SEBT). The test was used by Bressel et al.[43] to evaluate dynamic balance in collegiate athletes. The test consisted of eight lines of tape, marked at cm increments, each 120 cm in length extending from a common point at 45˚ angle increments. The participants centered their foot on the common point of intersection and were instructed to maintain single leg balance while performing a maximum reach with the opposite foot on one of the lines. The distance on each line was measured and defined as a percentage of the participant's leg length. A review by Gribble et al.[14] recommended that the SEBT be completed with shoes off due to the difficulty in standardizing participants testing in a variety of footwear. Both the NeuroCom SOT and the SEBT are recommended to be completed without footwear. The NeuroCom recommends non-slip socks in an attempt to avoid injury but also as a way to decrease the interference by footwear on somatosensory cues.[16] The SEBT is recommended to be completed without shoes in order to standardize the results.[14] These recommendations reveal the importance of footwear, or a lack thereof, in balance tests that will be discussed shortly.

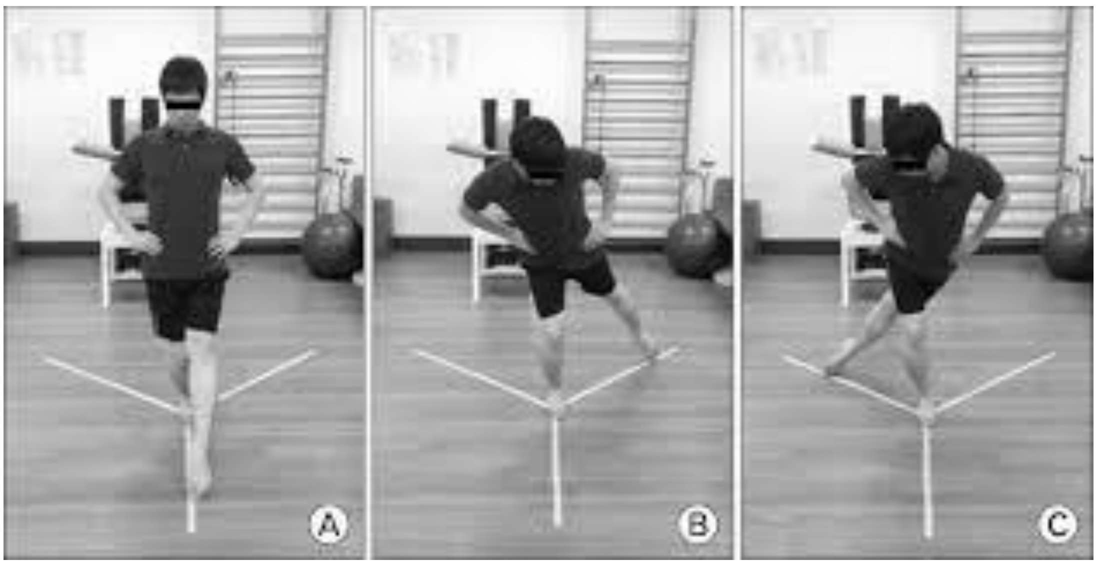

Figure 4. Star Excursion Balance Test[44]

The DPSI tests for dynamic postural stability in the most realistic manner. The single leg jump landing task (described in more detail below) is an athletic maneuver that mimics the actions of athletes in multiple sports. The use of a maneuver that mimics athletes in multiple sports allows for the most realistic and accurate testing and data. The use of the arms and vision are crucial in balance and coordination.[19, 30] These play a large role in dynamic postural stability and are discussed within the description of the DPSI protocols.

2.3.1 Dynamic Postural Stability as a Risk Factor for Injury

Deficits in dynamic postural stability have been identified as risk factors for multiple types of injuries. Paterno et al.[32] report that an increase in frontal plane load due to poor dynamic postural stability is a potential risk factor for ACL injury. This study used the Biodex system to evaluate dynamic postural stability and found that participants (n = 56) with deficits in dynamic postural stability were at a higher risk for ACL injury (OR = 2.3). No footwear recommendation was used or made in this study. Another study by Wikstrom et al.[12] reported that risk of development of chronic ankle instability might be identified by differences in dynamic balance. This study asked participants (n = 72) to complete a single leg jump landing task described by Ross et al.[6] No footwear recommendation was used or made in this study. A prospective study by Willems et al.[8] revealed that dynamic stabilizers are often compromised in males at risk for inversion ankle sprains. This study required participants to test in their self-selected sport shoes. The study consisted of 241 male physical education students (mean age = 18.3 ± 1.1 years). Participants were tested at the beginning of their education for multiple possible intrinsic risk factors including dynamic postural control. Lastly, a study by Guskiewicz et al.[23] revealed that participants who suffered a concussion within the past day had deficits in dynamic postural stability. Dynamic postural stability was tested for with the NeuroCom Sensory Organization Test.[16] Guskiewicz et al.[23] believe that the decrease in postural stability is due to ineffective communication from the visual and vestibular systems to the central nervous system. No footwear recommendation was used or made in this study when testing dynamic postural stability. With the known risk factors associated with dynamic postural stability, it is important to understand the relationship between protocols that test for dynamic postural stability deficits. A lack of comparability between data diminishes the ability to pinpoint the risk factors associated with dynamic postural stability across the literature. Unifying a protocol allows for all results to be amassed and pieced together in order to determine the most important risk factors related to dynamic postural stability.

2.4 METHODOLOGICAL CONSIDERATIONS

The protocol most often cited throughout the literature in relation to DPSI testing is based on the testing protocol introduced by Ross et al. as part of their time-to-stabilization (TTS) test.[6, 45] While Ross and Guskiewicz did not originally use this protocol to calculate DPSI scores, the protocol was later used by Wikstrom et al.[7] in the first calculations of DPSI.

2.4.1 Time to Stabilization

The TTS test was developed by Ross et al.[6] in 2003 in an attempt to measure how fast an individual can stabilize after a jump landing. They claimed that TTS, during a dynamic test, was significantly different between those with stable and unstable joints where those with unstable ankles had longer TTS. This was one of the first tests seen in the literature that used a jumping task to quantify dynamic postural stability.

The methods for the test were determined due to the commonality of athletes being required to jump during their activity. In order to maintain as much control as possible, the jump height was normalized to a percentage of the participant's maximum vertical jump while the jump distance was standardized for all participants to 70 centimeters (cm) from the center of the force plate. The maximum jump height was tested from the standardized jump distance and a Vertec marker was set at 50% of the maximum, directly above the force plate (Figure 1).[6]

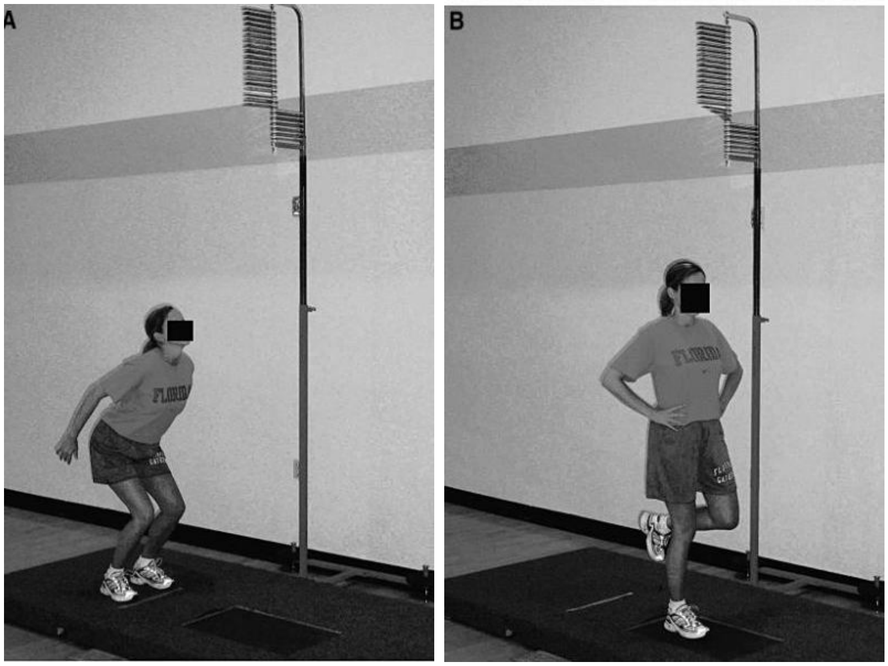

Figure 5. Protocol using normalized jump height[46]

The participant then jumped from the standard distance and touched the Vertec marker with their hand, which was aligned directly above the center of the force plate, before landing on the force plate. The participant jumped off two feet and landed on the dominant foot. The participant then found their balance on one foot and placed their hands on their hips as data was collected for twenty seconds. Components of peak GRF were used to calculate TTS. These components were selected based on Goldie et al.[5] who found that the amount the components varied during single leg stance could be an indicator of postural stability.[6] The three components were the vertical, medial-lateral, and anterior-posterior components.[7] Data was collected at a sampling rate of 180 Hz. A fast Fourier transformation analysis indicated that the raw analog signals for this type of test were below 30 Hz. In order to accurately capture the peak GRF, the higher Hz was selected.[6]

Initially, TTS data was proposed to be used as a measure for dynamic postural stability.[6] This type of measure could help clinicians determine if patients had any stability deficiencies and allow an appropriate treatment plan to be established. In addition, TTS could be used as a return-to-play measure for athletes. Since the origination of TTS, it has become a test that has been used to investigate areas such as the effects of ankle bracing and fatigue[47] and, healthy versus reconstructed anterior cruciate ligament (ACL).[48] This testing served as the starting point for the development of DPSI.

2.4.2 Wikstrom Protocol

Utilizing the TTS protocol by Ross and colleagues, Wikstrom et al.[7] developed the DPSI score in 2005. The same jump protocol was used but the application of the force plate information differed. This protocol will be referred to as the Ross/Wikstrom DPSI Protocol (RWDP) due to the integration of the Ross jumping protocol into the Wikstrom DPSI calculations. Wikstrom argues that, though TTS reports three measures of stability with its components of GRF, these components have no common link. This is an issue because it is not possible to clinically identify global dynamic postural stability changes.[7] It is also time consuming to analyze all of the data for each component.

The first DPSI study by Wikstrom et al.[7] attempted to conclude three things. First, to determine the best sampling window for the jumping task data collection; second, to determine the reliability and precision of the DPSI in healthy participants; third, to compare the reliability and precision of the DPSI with that of TTS.[7] It was found that altering the sampling window significantly affected the DPSI scores where a 3 second window had significantly higher (worse) scores than a 5 second window and a 5 second window had significantly higher scores than a 10 second window. The relationship between windows was found to be a decreasing linear function from 3 seconds to 10 seconds. The second finding was that the DPSI scores had a low standard error of the measurement (SEM = .03) and an excellent intersession reliability (ICC = .96).[7] These values were higher than the reported reliabilities for other stability tests such as the Biodex Stability System (BSS)[49, 50] (ICC = 0.82) and TTS (ICC = 0.80)[7]. These values reveal that the DPSI is a more reliable test than the BSS and TTS. It was also found that the DPSI was as accurate and precise as TTS but also had the ability to give the global measure of dynamic postural stability while also showing individual components. In conclusion, Wikstrom et al.[7] recommended the use of a 3-second sampling interval in order to mimic the functional activities of sport and the use of DPSI testing over TTS testing. No footwear recommendation was used or made in this study.

Other studies have utilized the RWDP since its creation. The RWDP was utilized by Wikstrom et al.[12] in a study investigating the difference in DPSI scores between uninjured controls and participants with chronic ankle instability (CAI). They found significantly lower ($p < 0.05$) DPSI scores (better) in the uninjured controls (0.281 ± 0.023) as compared to individuals with CAI (0.291 ± 0.022). The RWDP has proven to be the gold standard in the area of DPSI testing and has the potential to have a large impact on the clinical side as a diagnostic tool to predict if a patient is likely to develop chronic ankle instability.[12] With the understanding that deficits in dynamic postural stability are risk factors for injury, a precise and standardized dynamic postural stability test would help be an indicator of injury risk.

2.4.3 NMRL Protocol

With the desire for a more mobile DPSI testing protocol that required less equipment, Sell and colleagues at the Neuromuscular Research Laboratory (NMRL) modified the protocol used by

Wikstrom et al.[7] by normalizing jump distance rather than jump height.[1] Participants jumped over a 30-cm hurdle from a distance from the front edge of the force plate equal to 40% of their height. Participants were asked to place hands on hips when balance was attained and maintain single leg balance for 10 seconds.

Figure 6. Protocol using normalized jump distance[29]

This modification of the RWDP was also made in order to increase the deceleration forces which in turn increases the posterior ground reaction forces (PGRF).[1] It was revealed that a sharp deceleration or large PGRF is characteristic among injuries such as ACL injuries.[51] Including this increase in PGRF allows the task to mimic realistic injury scenarios. The NDP has been shown to have a very good reliability and precision (ICC = 0.86, SEM = 0.01).[1]

The reasoning behind the modifications to the RWDP for the NDP is not readily apparent. The normalization of jump distance rather than jump height by Sell et al.[1] was attributed to a similar protocol in a study by Padua et al.[52] that attempted to prove the Landing Error Scoring System (LESS) to be a valid and reliable screening tool for identifying individuals at risk for ACL injury. The study had participants jumping on to a force plate from a 30-cm high box. The distance to the force plate was normalized to 50% of the participant's height. The participants quickly rebounded from their landing on the force plate to perform a maximum vertical jump. The study used two standard video cameras (field setup), one along the sagittal plane and one along the frontal plane, to record the movements. A Flock of Birds electromagnetic motion analysis system controlled by Motion-Monitor software (Lab setup) was also used to analyze the kinematic data.[52] The goal of the study was to determine if the field setup would provide video that could be used for analysis comparable to the lab setup. This would allow for simpler and more accessible screening tests. No footwear recommendation was used or made in this study. The protocol, though similar in ways to the RWDP, was not evaluating DPSI and gave no reasoning for the use of a normalized jump distance. Sell et al.[1] would use this idea of normalized jump distance for their DPSI protocol modifications without any justification for the change. No justifications were given for the hurdle height of 30-cm either. An extensive search of the literature revealed no prior dynamic tasks involving a hurdle.

Since the implementation of the NDP, internal studies and pilot testing at the NMRL have been completed using this protocol. Sell et al.[29] looked at the differences in DPSI when a participant (armed forces operator) was under a loaded condition, comprised of standard U.S. Army clothing and equipment,[29] versus unloaded. This study was done specifically to look at military soldiers and see how the load was predisposing them to injury. They found the DPSI scores in the loaded condition (0.347 ± 0.045) were significantly higher/worse ($p < 0.001$) than those in the unloaded condition (0.324 ± 0.041). No footwear recommendation was used or made in this study. Another NMRL study by Pederson et al.[53] investigated the differences in DPSI scores between participants with functional ankle instability (FAI) and healthy controls. They found that participants with FAI (0.400 ± 0.030) had significantly higher ($p = 0.004$) DPSI scores than the healthy controls (0.350 ± 0.040). No footwear recommendation was used or made in this study. A third study by Whitehead et al.[21] investigated the effect of footwear on NDP DPSI scores. The study revealed that DPSI scores were significantly lower ($p < 0.001$) in participants completing the NDP in minimalist running shoes (0.359 ± 0.026) versus standard athletic shoes (0.376 ± 0.026). Lastly, a study by Lawson et al.[54] utilized the NDP with participants in the shod condition. It was found that these participants had DPSI scores of 0.319 ± 0.044.

2.5 THE EFFECT OF PROTOCOLS

The differences between the RWDP and the NDP could have an effect on the comparability of the data being collected in studies using different protocols. The RWDP uses the normalized jump height to 50% of the participant's maximum jump.[7] This is compared to the NDP which uses a 30-cm hurdle as jump height.[1] A second difference between protocols is that the NDP normalized jump distance to 40% of participant's height to the front of the force plate where the RWDP had a standardized jump distance for all participants of 70 cm to the center of the force plate.[1, 7] A study by Heebner et al.[18] reported that increased jump distance produces increased landing demand that leads to increased vertical and anterior-posterior GRFs. With the RWDP standardized at a 70 cm jump distance, a participant in a study that uses the NDP would have to be approximately 4 feet tall in order to jump from the same distance. This being said, the NDP requires a greater jump distance compared to the RWDP for a vast majority of participants. According to Heebner et al., the NDP should produce greater vertical and anterior-posterior GRFs due to this increased jump distance. Increased GRFs may lead to an increased DPSI score when testing with the NDP. Heebner et al.[18] had participants complete the testing in participant self-selected athletic shoes.

Due to these differences in protocols, a few changes in the participants' jump occurred. During pilot testing for this study, participants reported that during the RWDP, they focused their vision on the 50% maximum jump Vertec marker, which they were required to touch. This focus did not allow them to attain a solid visual of the force plate prior to landing. In the NDP, participants said they focused their vision on the force plate landing site for nearly the entire jump task. A study by Santello et al.[19] found that proprioceptive and vestibular information could not fully compensate for a lack of visual information in a landing activity. The RWDP requires participants to jump and touch the overhead Vertec marker. Compared to the simple hurdle jump required in the NDP, this hand motion in the RWDP is more attentionally demanding. According to the previously mentioned study by Kerr et al.,[17] the difference in hand motion between protocols may significantly affect the attention requirement for participants which may significantly effect DPSI scores. Another difference between protocols is the use of the upper body. In the RWDP, participants are forced to reach overhead in order to touch the Vertec marker. This reach leads to a higher displacement of the arms prior to landing. It was reported by Shetty et al.[30] that arm movements during a vertical jump increase maximum take-off force and decrease landing impact force. It is possible that the arm movements in the RWDP, which are restricted due to the requirement of touching the overhead Vertec marker, increase the DPSI score. The arms are not able to be used solely as stabilizers in this jumping task as they are in the NDP jumping task because they must be used to touch the Vertec marker. The NDP allows the arms to be used exclusively for balance. With this information, it is possible that the different arm movements between protocols have an effect on DPSI scores as well.

Though there are significant differences in DPSI scores between studies that use the RWDP versus the NDP, it is believed that there will be a correlation between the RWDP and NDP DPSI scores. There will be a correlation because each participant is completing all four trials, acting as their own control. It is believed that their level of dynamic postural stability will remain constant, only their DPSI scores will change due to the different protocols. It is believed that each participant will have a similar difference in DPSI scores between protocols, resulting in a correlation.

Table 1. The differences between protocols

	RWDP	NDP
Jump Height	50% maximum vertical	30-cm hurdle
Jump Distance	70 cm to center of force plate	40% participant height to front of force plate
Arm Mechanics	One arm to reach a vertical marker	No specific arm movement
Attention	Focus on reaching a vertical marker and landing	Focus on clearing a hurdle and landing

2.6 THE EFFECT OF FOOTWEAR

An area of DPSI that has not been thoroughly investigated is the effect of footwear. A recommendation has not been made regarding footwear in any study. No recommendations on footwear were made by Wikstrom et al.[7] in the original DPSI study, and no recommendations were made by Ross et al.[6] in their development of TTS. When developing the NDP, Sell et al.[1] also did not consider controlling for footwear. In a recent study, footwear's effect on DPSI scores were investigated using the NDP. Whitehead et al.[21] found that there was a significant difference in DPSI scores between athletic shoes and minimalist shoes within the same participant. Minimalist shoes were found to have significantly lower DPSI scores, indicating better dynamic postural stability.[21] They also found significant differences between military boots and minimalist footwear where minimalist shoes had significantly lower DPSI scores again.[21] These results show that the footwear itself has a significant effect on DPSI scores. A study by Rose et al.[20] showed similar results, in that a significant difference between DPSI scores in a barefoot condition. Compared to a standard athletic shoe or minimalist shoe, barefoot had significantly lower DPSI scores than either of the other conditions.[20] Footwear has also been reported to decrease proprioception in the foot, specifically in the plantar region.[55] This plantar proprioception has been reported to help the central nervous system to increase stability and avoid injury. A decrease in this proprioception in turn, would decrease stability. Without a standardized footwear recommendation for DPSI testing, the effects of footwear cannot be accounted for and the results cannot be confidently compared. Studies that do not share the same standardized footwear cannot be compared even if the same protocol is utilized.

It is then an issue to recommend a standardized footwear for all studies. Unless every study using DPSI uses the same type of footwear, results are not comparable. The simplest way to control for the potential confounding effect of footwear is to carry out all DPSI protocols in a barefoot protocol. Lieberman et al.[56] showed that the barefoot condition leads to an increase in forefoot striking versus shod condition. Forefoot striking has been shown to decrease ground reaction forces, which directly affect DPSI scores.[56] Combining all of these results, DPSI is effected by footwear and needs to be controlled in all DPSI testing. It is believed that this recommendation should be for a barefoot condition, similar to recommendations for other types of balance assessments.

2.7 CLINICAL IMPLICATIONS

There are many possibilities for clinical implications of DPSI. Due to good reliability and precision, DPSI could be used to detect deficits and changes in dynamic postural stability in clinical evaluations.[7] Clinicians could use the test to evaluate a patient's dynamic postural stability upon their first evaluation, implement an appropriate intervention, and then retest DPSI at the completion of the intervention. Willems et al.[8, 9] showed that decreased postural control is a risk factor for ankle injury. These findings lead to another use for DPSI as a prospective tool to analyze risk factors for injury in athletic populations whose activities are best simulated by the DPSI protocols.[1] This could potentially reveal the changes in dynamic postural stability in the patient due to the intervention.

2.8 SUMMARY

Balance and postural stability are widely studied topics throughout the literature. Both are crucial in everyday life and activities. With poor postural stability comes the risk of falls and injury.[33] Postural stability is commonly broken into static and dynamic postural stability. Both static and dynamic postural stability have been identified as potential risk factors for injury and are both tested for in multiple ways.[6, 8, 10-12, 32] Considered a more challenging category of testing, dynamic postural stability tests can be used to mimic the movements and activities of athletes.[1] The dynamic postural stability index has been developed to quantify a participant's dynamic postural stability and identify potential risk for injury.[13]

With multiple jump protocols and no footwear recommendation, testing using the DPSI across the literature is difficult or impossible to compare. Studies have shown a significant difference in DPSI values between the RWDP and the NDP.[5],[12] Differences in DPSI scores reveal the need to standardize a protocol for all DPSI testing throughout the literature in order to have comparable data that can be compiled to have the strongest knowledge base available. Other studies have revealed the significant difference within a participant when using varying footwear.[21],[20] With this difference, a recommendation on footwear within all DPSI protocols should be made in order to keep all studies similar and their data comparable.

3.0 METHODS

3.1 EXPERIMENTAL DESIGN

The study utilized a cross-sectional, observational design to determine the difference in DPSI scores between protocols with the participants as their own controls. The design was also chosen to determine the effect that shod and barefoot conditions had on DPSI scores.

3.2 PARTICIPANT RECRUITMENT

The study was approved by the Human Research Protection Office (HRPO) at the University of Pittsburgh prior to implementation of all research procedures. Participants were recruited from a local university and surrounding communities. Study flyers, social media, and word of mouth recruitment strategies were used, and interested participants called or emailed the NMRL for further information.

3.3 PARTICIPANT CHARACTERISTICS

3.3.1 Inclusion Criteria

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.

3.3.2 Exclusion Criteria

Interested persons were excluded from participation if they have 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.

3.4 SAMPLE SIZE JUSTIFICATION

An *a priori* power analysis was performed using G*Power 3 statistical software.[57] Previous data from a study that utilized the NDP to collect measures of DPSI was used in calculating a sample size for this study.[21] Utilizing previously reported data from Whitehead et al.,[21] (athletic shoe DPSI = 0.376 ± 0.026; minimalist footwear DPSI = 0.359 ± 0.026; $p < 0.001$) a large effect size of $d = 0.65$ was assumed for a two-tailed t-test that compared the difference between two dependent means,[58] along with an alpha level of $p = 0.05$, and a desired power of 80%, a total sample size of

21 was necessary.[59] To account for 15% attrition or data loss, four additional subjects were recruited, bringing the total sample size to 25 subjects.

3.5 INSTRUMENTATION

All items listed below were utilized during the data collection portion of the study. Subjects reported to the Neuromuscular Research Laboratory (NMRL) for a single test session.

3.5.1 Demographic Data

Data collected for subject demographics included gender, age, height (shod and barefoot), and weight (shod and barefoot), which was recorded on a demographic data collection sheet (Appendix A). A wall-mounted stadiometer (Seca, Hanover, MD) was used to collect height, and an electronic scale (Cosmed USA Inc., Chicago, IL) was used to collect weight.

3.5.2 Force Plates

A piezoelectric force plate (Kistler 9286A, Amherst, NY) was used to calculate GRF data, which was used in the assessment of dynamic postural stability. 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.

3.5.3 Nexus/Vicon

Trials were collected using the Vicon Nexus Software (Vicon Motion Systems Inc., Centennial, CO). Force plate data was amplified and passed through an analog to digital board (DT3010, Digital Translation, Marlboro, MA) before being stored on a personal computer.

3.5.4 Vertec

A Vertec vertical jump device (Sports Imports, Columbus, OH) was used to calculate each participant's maximum vertical jump prior to DPSI testing. The Vertec was then utilized as a reach point for the participants during the RWDP when they were required to reach and touch the point at 50% of their maximum jump prior to landing.

Figure 7. Vertec[60]

3.6 TESTING PROCEDURES

Participants reported to the NMRL 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 of Pittsburgh's HRPO. The principal investigator thoroughly described the testing procedures, risks, benefits, and confidentiality while allowing the participant to ask questions or voice concerns. Following this discussion, the participant confirmed their desire to participate in the study or was given a chance to withdraw. Those wishing to continue reconfirmed their eligibility for the study and those who were eligible provided written consent.

All demographic data was collected prior to testing. This included participant's age, height, weight, ankle stability, and activity rating. The demographic and data collection sheet, ankle instability questionnaire, athletic background, shoe information, pain scale, and the activity rating scale[61] can be found in Appendix A. 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 to be completed, 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.[7] Due to the potential changes in jumping and landing mechanics from pain during repeated barefoot jumps and landings, a pain scale was used to record the participant's perceived pain level between conditions. All participants were required to use a countermovement jump with the use of arms. A study by Harman et al.[62] found that jumps with the use of arms and a countermovement resulted in the largest power as compared to jumps without the use of arms or a countermovement. In order to control all participant's jump power, all participants were required to use the countermovement jump with arms.

3.6.1 Ross/Wikstrom DPSI Protocol

The RWDP was tested as described by Ross et al.[6] and Wikstrom et al.[7] All participants were measured for their maximum vertical jump as described by Wikstrom et al.[63] Maximum vertical jump was measured using a Vertec vertical jump device and was measured for both the shod and barefoot conditions. The maximum vertical jump was determined as the difference between a subject's maximum reach height while standing on their tip-toes and their maximum reach height during a jump from 70cm.[63] Three trials of maximum jump height were completed and the highest jump was recorded. Measurements were in increments of 1.27 cm. The jump protocol described by Ross and Guskiewicz[6] was used to complete the RWDP. 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.

There were five reasons that a jump trial may have been cancelled and repeated.

- If the participant did not touch the overhead Vertec marker.
- If the participant failed to land with the dominant foot fully on the force plate.
- If the participant landed on the dominant foot but failed to balance and touched the ground with any other part of their body.

- If the participant landed on the dominant foot but the foot did not stay in one position. This included a hop or slide.
- If there was an issue with the data collected for that trial, it was discarded and repeated.

Three successful trials were collected for each condition, barefoot and shod, for a total of six collected trials using RWDP. The number of successful and unsuccessful trials was recorded as the participant completed the task.

3.6.2 NDP

A jump protocol described by Sell et al.[1] was used for the NDP. 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, for a total of six collected trials using NDP. The specific variables being analyzed were the average DPSI score across the collected trials. The number of successful and unsuccessful trials was recorded as the participant completed the task.

One would think with such similar collection procedures the tests should yield comparable data, but it was believed that this seemingly subtle difference in protocol would change the demands of the task considerably, affecting scores significantly.

3.7 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).

3.7.1 DPSI Calculation

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).[1, 7, 34] The following formula was used to calculate DPSI:[64]

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

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.[64] All stability indices were calculated using the first three seconds of GRF data following initial contact with the force plate. The average of three successful trials was used to calculate DPSI scores during each lab visit. Analog data collected from the force plate during the jump trials was exported by Vicon Nexus Software and processed through a Matlab script.

3.8 STATISTICAL ANALYSIS

All variables were analyzed using SPSS (v23, SPSS Inc., Chicago, IL), including those generated with custom Matlab scripts. Descriptive statistics were calculated for all variables (means, standard deviations, medians, interquartile ranges). All data was examined for normality using the Shapiro-Wilk test, and normally distributed data was analyzed using paired samples t-tests of the deltas to compare mean differences between the RWDP and the NDP along with the differences between footwear. Data that was not normally distributed was analyzed using a non-parametric Wilcoxon Signed Ranks test on the deltas to compare mean differences. Participants were compared in RWDP scores and NDP scores along with scores in both tests with varying footwear. A Pearson Correlation Coefficient was used to determine if a correlation existed between normally distributed data. A Spearman Correlation Coefficient was used to determine if a correlation existed between non-normally distributed data. An alpha level of 0.05, 2-sided was set a priori as a significance level for statistical analyses.

4.0 RESULTS

4.1 DEMOGRAPHIC INFORMATION

A total of 25 participants volunteered for this study. Each individual met the inclusion criteria and did not report meeting any of the exclusion criteria. No participants were lost during testing. An *a priori* analysis determined that a sample size of 21 would be sufficient for completion of data collection. The data for all 25 participants was included in data analysis.

Table 2 presents the demographic data. Gender was evenly distributed at 13:12 respectively. All participants were between the ages of 18 and 35. Only one participant complained of pain and stated it was a 2 out of 10 following two protocols. The average Cumberland Ankle Instability of participants was under a score of 5 (4.92 ± 5.678) with no participant spraining their ankle within a year of testing. The average Sports Activity Rating was 90 ± 8.292 meaning each participant exercised at least three times per week. There were no significant correlations found between the Cumberland Ankle Instability and DPSI scores or the Sports Activity Rating scores and DPSI scores. 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. No shoes had been worn for greater than 3 years (0.823 ± .679). No significant difference was found between genders in any condition ($p > 0.123$).

Table 2. Demographics

	N	Mean	Std. Deviation
Age	25	22.12	4.226
HeightShod (cm)	25	180.9	10.6
HeightBF (cm)	25	178.3	11.1
WeightShod (kg)	25	76.16	19.47
WeightBF (kg)	25	75.60	19.40

Table 3. DPSI Descriptives

		RWDPS_DPSI	RWDPBF_DPSI	NDPS_DPSI	NDPBF_DPSI
N		25	25	25	25
Mean		.3438	.3365	.3470	.3295
Median		.3429	.3314	.3420	.3246
Std. Deviation		.0333	.0275	.0299	.0329
Percentiles	25	.3174	.3166	.3272	.3069
	75	.3686	.3530	.3594	.3388

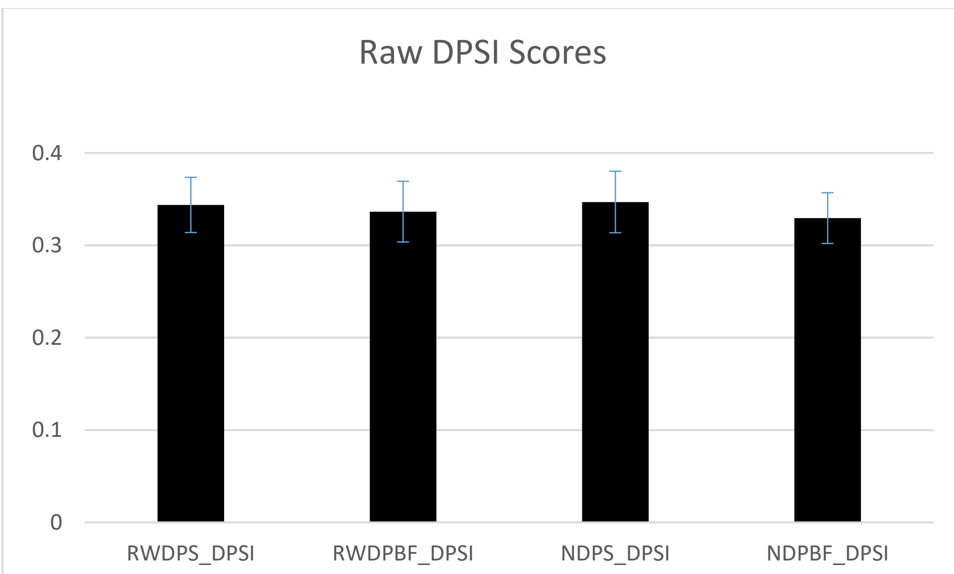

Figure 8. DPSI Descriptives

4.2 COMPARISON OF SHOD DPSI SCORES BETWEEN PROTOCOLS

4.2.1 Comparing means of shod DPSI scores between protocols

DPSI scores were collected in the shod condition with both the NDP and the RWDP. Participants successfully completed 3 trials of each protocol in the shod condition. The DPSI scores were used to determine if any significant differences were found between protocols in the shod condition and to determine if there was a significant correlation between the protocols in the shod condition.

To compare the means of the shod DPSI data scores, all data was first tested for normality using the Shapiro-Wilk test (Table 4). All shod DPSI data was found to be normally distributed ($p = 0.793$). A paired samples t-test was used to analyze the normally distributed data and no significant difference was found between the shod conditions of each protocol (RWDPS: 0.3438 ± 0.0333; NDPS: 0.3470 ± 0.0299, $p = 0.654$). On average, each participant required 4.12 ± 1.590 attempts in the NDPS and 5.24 ± 2.296 attempts in the RWDPS to complete three successful trials.

Table 4. Shapiro-Wilk test for Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
RWDP: BF vs S	.977	25	.831
NDP: BF vs S	.969	25	.622
RWDPBF vs NDPBF	.958	25	.383
RWDPS vs NDPS	.976	25	.793

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 5. Paired T-test Results for Significance

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 RWDPS vs NDPS	-.0032	.0353	.0071	-.0178	.0114	-.454	24	.654
Pair 2 RWDPBF vs NDPBF	.0070	.0285	.0057	-.0048	.0187	1.224	24	.233
Pair 3 NDPBF vs NDPS	-.0175	.0141	.0028	-.0233	-.0116	-6.199	24	.000
Pair 4 RWDPBF vs RWDPS	-.0073	.0206	.0041	-.0158	.0012	-1.767	24	.090

4.2.2 Correlations of shod DPSI scores between protocols

Data was normally distributed in both the NDPS and RWDPS ($p = 0.262$, $p = 0.268$ respectively). With normal data, a Pearson Correlation test (Table 7) determined there was no significant correlation between protocols in the shod condition ($r = 0.382$, $p = 0.060$).

Table 6. Shapiro-Wilk test for Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
RWDPS_DPSI	.951	25	.268
RWDPBF_DPSI	.972	25	.699
NDPS_DPSI	.951	25	.262
NDPBF_DPSI	.909	25	.029

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

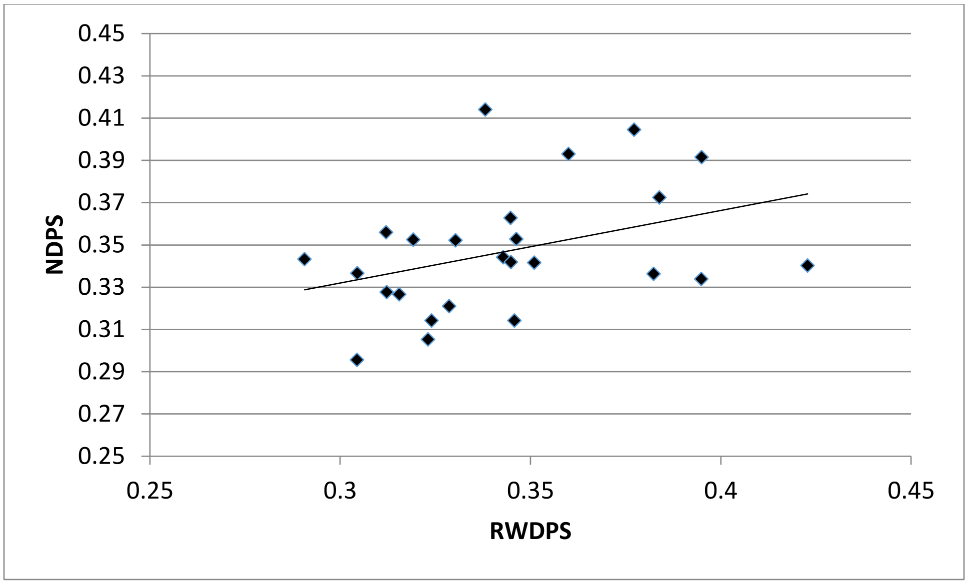

Figure 9. Correlation between RWDPS and NDPS

Table 7. Correlation of shod conditions between protocols

		RWDPS_DPSI	NDPS_DPSI
RWDPS_DPSI	Pearson Correlation	1	.382
	Sig. (2-tailed)		.060
	N	25	25
NDPS_DPSI	Pearson Correlation	.382	1
	Sig. (2-tailed)	.060	
	N	25	25

4.3 COMPARISON OF BAREFOOT DPSI SCORES BETWEEN PROTOCOLS

4.3.1 Comparing means of barefoot DPSI scores between protocols

The DPSI scores were collected in the barefoot condition with both the NDP and the RWDP. Participants successfully completed 3 trials of each protocol in the barefoot condition. The DPSI scores were used to determine if any significant differences were found between protocols in the barefoot condition and to determine if there was a significant correlation between the protocols in the barefoot condition.

All barefoot DPSI data was found to be normally distributed ($p = 0.383$). A paired samples t-test was used to analyze the normally distributed data and no significant difference was found between the barefoot conditions of each protocol (RWDPBF: 0.3365 ± 0.0275; NDPBF: 0.3295 ± 0.0329, $p = 0.233$). On average, each participant required 3.92 ± 1.441 attempts in the NDPBF and 5.08 ± 2.120 attempts in the RWDPBF to complete three successful trials.

4.3.2 Correlations of barefoot DPSI scores between protocols

Data was non-normally distributed in the NDPBF ($p = 0.029$) and normally distributed data in the RWDPBF ($p = 0.699$). With non-normal data, a Spearman Correlation test (Table 8) was used and it was determined that there was a significant correlation between protocols in the barefoot condition ($r = 0.565$, $p = 0.003$).

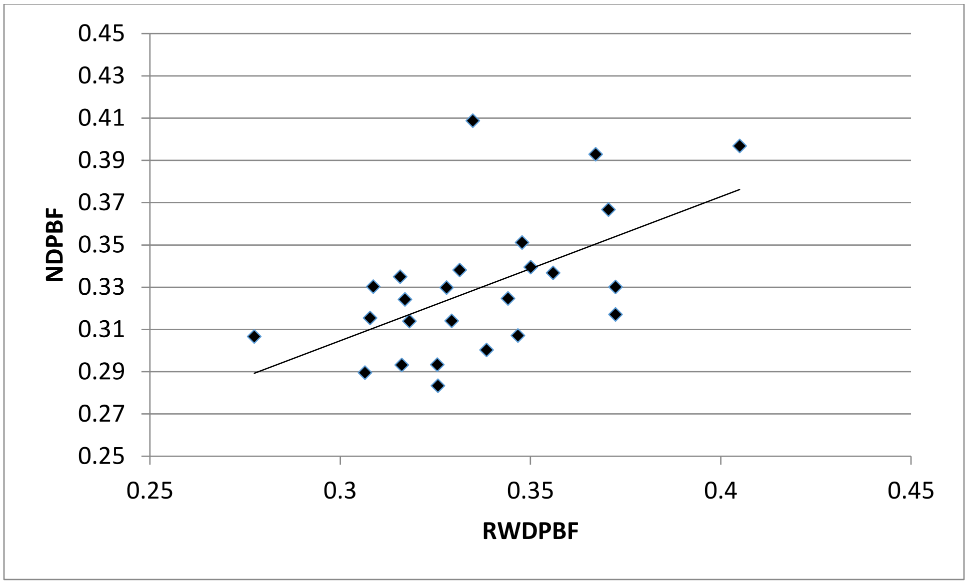

Figure 10. Correlation between RWDPBF and NDPBF

Table 8. Correlation of barefoot conditions between protocols

		RWDPBF_DPSI	NDPBF_DPSI
RWDPBF_DPSI	SpearmanCorrelation	1	.565**
	Sig. (2-tailed)		.003
	N	25	25
NDPBF_DPSI	Spearman Correlation	.565**	1
	Sig. (2-tailed)	.003	
	N	25	25

**. Correlation is significant at the 0.01 level (2-tailed).

4.4 COMPARISON OF DPSI SCORES WITHIN THE RWDP

4.4.1 Comparing means of DPSI scores within the RWDP

DPSI scores were collected in the shod and barefoot conditions with the RWDP. Participants successfully completed 3 trials in each condition. The RWDP DPSI scores were used to determine if any significant differences were found between conditions and to determine if there was a significant correlation between the conditions within the RWDP.

All RWDP DPSI data was found to be normally distributed ($p = 0.831$). A paired samples t-tests were used to analyze the normally distributed data and no significant difference was found between the RWDP shod and barefoot conditions (RWDPS: 0.3438 ± 0.0333; RWDPBF: 0.3365 ± 0.0275, $p = 0.090$).

4.4.2 Correlations of DPSI scores within the RWDP

Data was normally distributed for the shod and barefoot conditions in the RWDP ($p = 0.268$, $p = 0.699$ respectively). With normal data, a Pearson Correlation test (Table 10) was used and it was determined that there was a significant correlation between the shod and barefoot conditions in the RWDP ($r = 0.786$, $p < 0.001$).

Figure 11. Correlation between RWDPS and RWDPBF

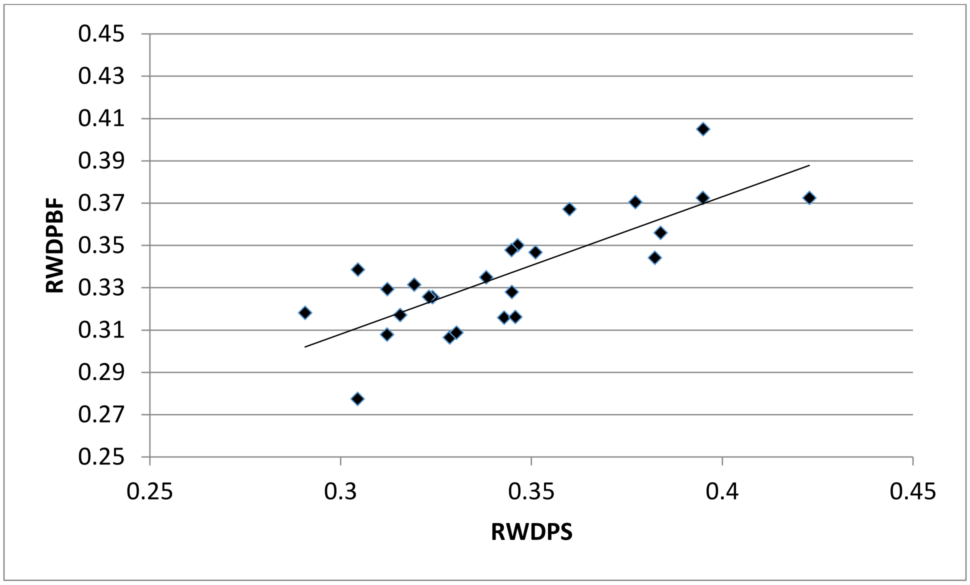

Table 9. Correlation of shod and barefoot conditions within the RWDP

		RWDPS_DPSI	RWDPBF_DPSI
RWDPS_DPSI	Pearson Correlation	1	.786**
	Sig. (2-tailed)		.000
	N	25	25
RWDPBF_DPSI	Pearson Correlation	.786**	1
	Sig. (2-tailed)	.000	
	N	25	25

**. Correlation is significant at the 0.01 level (2-tailed).

4.5 COMPARISON OF DPSI SCORES WITHIN THE NDP

4.5.1 Comparing means of DPSI scores within the NDP

DPSI scores were collected in the shod and barefoot conditions with the NDP. Participants successfully completed 3 trials in each condition. The NDP DPSI scores were used to determine if any significant differences were found between conditions and to determine if there was a significant correlation between the conditions within the NDP.

All NDP DPSI data was found to be normally distributed ($p = 0.622$). A paired samples t-test was used to analyze the normally distributed data and it was determined that there was a significant difference between the NDP shod and barefoot conditions (NDPS: 0.3470 ± 0.0299; NDPBF: 0.3295 ± 0.0329, $p < 0.001$).

4.5.2 Correlations of DPSI scores within the NDP

Data was non-normally distributed in the NDPBF ($p = 0.029$) and normally distributed in the NDPS ($p = 0.262$). With non-normal data, a Spearman Correlation test (Table 9) was used and it was determined that there was a significant correlation between the shod and barefoot conditions in the NDP ($r = 0.870$, $p < 0.001$).

Figure 12. Correlation between NDPS and NDPBF

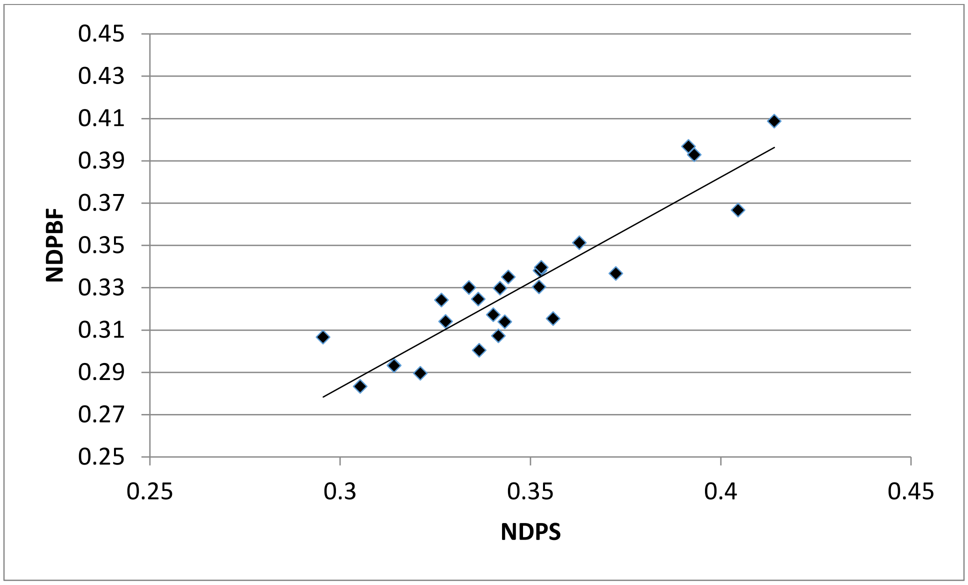

Table 10. Correlation of shod and barefoot conditions within the NDP

		NDPS_DPSI	NDPBF_DPSI
RWDPS_DPSI	Spearman Correlation	1	.870**
	Sig. (2-tailed)		.000
	N	25	25
NDPBF_DPSI	Spearman Correlation	.870**	1
	Sig. (2-tailed)	.000	
	N	25	25

**. Correlation is significant at the 0.01 level (2-tailed).

5.0 DISCUSSION

5.1 THE SHOD CONDITION BETWEEN PROTOCOLS

The purpose of this study was to compare and correlate two different single leg jumping tasks which utilize the DPSI and to determine the effect of footwear on each in a young, athletic population. Stated in hypothesis 1a, it was believed there would be a significant difference in the shod DPSI scores between the RWDP and the NDP. Specifically, the shod NDP would have significantly lower DPSI values than the shod RWDP. Stated in hypothesis 1b, it was also believed there would be a significantly positive correlation between the protocols within the shod condition. It was found that the shod condition between the NDP and the RWDP were not significantly different ($p = .654$) and were also not correlated ($p = .060$). The results did not support the original hypothesis.

The many differences between the protocols lead to hypothesis 1a. These differences included that the NDP utilized a jump distance normalized to the participant's height and a standardized jump height, while the RWDP standardized jump distance and normalized participant's jump height to their maximum vertical jump. According to Heebner[18], increased jump distance would lead to increased landing demands, which would increase the vertical and anterior/posterior GRF's. As these GRF values are part of the DPSI calculation, an increase in GRF's would lead to increased DPSI scores. In this study, all participants were required to jump from a further distance in the NDP than the RWDP, since NDP jumps were based on their height. The increase in jump distance was predicted to increase the DPSI scores but this trend was not seen in the current study.

Another difference between protocols was the difference between the participant's use of vision. Due to the use of the normalized jump height in the RWDP which required participants to 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 vision on the landing site for the majority of the jump. According to Santello et al.[19], proprioception and vestibular feedback cannot fully compensate for the lack of visual feedback during a landing activity. A study by Sell et al.[1] reported that static balancing in the eyes closed condition leads to over two times the deviation in the anterior-posterior, medial-lateral, and vertical directions as compared to the eyes open condition. With this information, it was believed that the RWDP would result in poorer landings than the NDP due to the limits on vision during the jumping task. This prediction was not seen in the results as there was no significant difference between protocols. It seems that the impact of vision, as seen in previous studies, may not be as apparent in the RWDP. The previous studies focus on the eyes closed condition where the RWDP does not requires participants to keep their eyes closed rather forces their attention to be focused away from the landing zone. This reveals that the complete lack of vision affects landing but the lack of attention on the landing zone does not. As long as participants maintain the eyes open condition, regardless of their attention, no significant difference in DPSI scores should be seen.

Lastly, arm movements were different 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. According to Shetty et al.[30], arm movements in vertical jumps increase the maximum takeoff force and decrease the landing impact. There are limited studies investigating the effect of arm movements during single leg jump landing tasks. It was believed 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.

Hypothesis 1a was rejected due to the current studies results showing no significant difference between the NDP and RWDP in the shod condition. This reveals that the previously mentioned differences between protocols did not have a significant effect on the DPSI scores. Though jump distance, vision, and arm mechanics have been seen to significantly effect landing in previous studies, it did not significantly effect DPSI scores between the NDP and the RWDP in the shod condition.

Hypothesis 1b was believed to be true because, though many differences between protocols existed, the participants were completing each protocol and being used as their own control. 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 numbers were expected to vary between protocols but be significantly correlated due to the constant nature of their dynamic postural stability.

Hypothesis 1b was rejected with no significant correlation between DPSI scores in the NDP and RWDP in the shod condition. This reveals that the shod DPSI scores cannot be compared between protocols.

5.2 THE BAREFOOT CONDITION BETWEEN PROTOCOLS

Stated in hypothesis 2a, it was believed that there would be a significant difference between the protocols within the shod condition with the NDP DPSI scores being significantly lower. Stated in hypothesis 2b, it was also believed that there would be a significantly positive correlation between the protocols within the barefoot condition. It was found that the barefoot condition between the NDP and the RWDP were not significantly different (p = .233) and were correlated (p= .003). The results of the current study do not support hypothesis 2a but do support hypothesis 2b.

In reference to the differences stated in section 5.1 between the NDP and the RWDP, it is again seen that the effects of jump distance, vision, and arm mechanics did not have a significant effect on the barefoot DPSI scores between NDP and RWDP. The average normalized jump distance for the NDP was 33.06 centimeters longer than the standard jump distance in the RWDP.

Hypothesis 2b was accepted with a significant positive correlation between protocols in the barefoot condition. This reveals that barefoot DPSI scores can be compared between protocols by means of a correlation coefficient. For future studies, if single leg jump landings are completed in the barefoot condition, the NDP and RWDP results will be correlated with the RWDP DPSI scores being significantly higher but correlated at $r = 0.565$ to the NDP DPSI scores ($p = 0.003$).

5.3 SHOD AND BAREFOOT WITHIN THE RWDP

Stated in hypothesis 3a, it was believed that there would be a significant difference between the shod and barefoot conditions within the RWDP. Stated in hypothesis 3b, it was also believed that there would be a significantly positive correlation between the shod and barefoot conditions within the RWDP. It was found that there was no significant difference between the shod and barefoot conditions within the RWDP (p = .090). It was also found that there was a significant positive correlation between the shod and barefoot condition within the RWDP (p = .000). This leads to hypothesis 3a being rejected and 3b being accepted.

Hypothesis 3a was rejected due to the current studies results showing no significant difference in DPSI scores between the shod and barefoot condition in the RWDP as was assumed due to the reported findings by Rose et al.[20] who investigated the difference in DPSI scores between the barefoot, standard athletic shoe, and minimalist conditions utilizing a jump-landing protocol with a standard jump distance. It was reported that the barefoot condition resulted in the significantly lowest DPSI scores. This reveals that the RWDP does not produce as sensitive of DPSI scores as the NDP. With strong evidence that there is expected to be a difference in DPSI scores between the shod and barefoot condition, a result showing no significant difference reveals this lack of sensitivity in the RWDP.

Hypothesis 4b was accepted due to the results of the current study revealing that shod and barefoot DPSI scores collected with the RWDP are correlated and may be compared with the use of a correlation coefficient. In relation to DPSI results from previous studies which utilized the RWDP, a study by Liu et al.[65] utilized the RWDP in the barefoot condition and reported DPSI scores of 0.396 ± 0.243. Another study by Wikstrom et al.[46] utilized the RWPD in the barefoot condition and reported DPSI scores of 0.39 ± 0.018. Another study by Wikstrom et al.[12] utilized the RWDP in an unreported footwear condition and reported DPSI scores of 0.281 ± 0.023. These large variations may be due to changes in RWDP calculations in the recent past. It is important to identify the DPSI equation being used in order to most accurately compare results between studies.

5.4 SHOD AND BAREFOOT WITHIN THE NDP

Stated in hypothesis 4a, it was believed that there would be a significant difference between the shod and barefoot conditions within the NDP. Stated in hypothesis 4b, it was also believed that there would be a significantly positive correlation between the shod and barefoot conditions within the NDP. It was found that there was a significant difference between the shod and barefoot conditions within the NDP (p = .000). It was also found that there was a significant positive correlation between the shod and barefoot condition within the NDP (p = .000). This leads to both hypotheses 4a and 4b being accepted.

Previous studies which investigated the difference in DPSI scores between the shod and barefoot condition lead to hypothesis 4a. Whitehead et al.[21] reported that there was a significant difference in DPSI scores between standard athletic shoes, military boots, and minimalist footwear (.376 ± .026; .362 ± .027; .359 ± .026, respectively). It was reported that the minimalist footwear group had significantly lower DPSI scores as compared to the standard athletic shoes and military boots. It was found that varying types of shoes results in significantly different DPSI scores. The results of the current study also reveal a significant difference in DPSI scores between footwear conditions. A second study by Lieberman et al.[56] reported that the barefoot condition resulted in increased forefoot striking during landing as compared to the shod condition. Forefoot landing was reported to lead to decreased GRFs, which are directly associated with DPSI scores. It was hypothesized that, with these reported effects of barefoot landing, the barefoot condition would result in lower DPSI scores than the shod condition. Our findings support the report that the barefoot condition leads to increased forefoot striking and therefore lower DPSI scores, specifically in the NDP. It can be concluded that varying footwear results in significantly different NDP DPSI scores. Many studies have investigated dynamic postural stability through the NDP and many conclusions made based on these DPSI studies, it is necessary to re-examine any conclusions made based on this data. If footwear was not controlled, inaccurate results may have been collected and analyzed, leading to inaccurate conclusions. Looking forward, it is important to standardize footwear in all studies which utilize the NDP in an attempt to minimize the effect of footwear on the DPSI results.

Hypothesis 4a was accepted due to the current studies results showing that the barefoot condition, within the NDP, results in significantly lower DPSI scores than the shod condition. This supports the results reported in the studies above by Whitehead et al.[21] and Lieberman et al.[56] In the shod condition, participants have decreased proprioceptive feedback from the foot which would decrease the participants stability.[55] The claim that being barefoot may increase this proprioceptive feedback from the foot and lead to lower DPSI scores is supported by the findings of Lieberman et al.[55] who report that the shod condition decreases proprioceptive feedback.

Hypothesis 4b was accepted, though the footwear conditions are significantly different within the NDP, the current studies results show they can be compared with the use of a correlation coefficient. In relation to DPSI results from previous studies which utilized the NDP, a study by Whitehead et al.[21] utilized the NDP in the shod condition and reported DPSI scores of 0.359 ± 0.026. Another study by Pederson et al.[53] utilized the NDP and the shod condition as well. They reported DPSI scores of 0.350 ± 0.040. Lastly, a study by Sell et al.[1] utilized the NDP and reported DPSI values of 0.348 ± 0.035. These values are close to the DPSI values collected in this study, which reveals good consistency between studies.

5.5 LIMITATIONS

The current study was not without limitations. One limitation was that participants jumped in 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 from minimalist shoes to the bulkier, standard running shoe. This difference, though reflective of the previous literature, may significantly affect the DPSI scores.

In a previous study by Wikstrom et al.[34] it was determined that females have significantly higher DPSI values than males. 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, this issue was accounted for.

Studies have shown that balance decreases as age increases.[66] 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 protocols, it could influence the data. The ages of the participants in this study are young and comparable to other studies which also utilize these protocols.[1, 34]

5.6 CLINICAL SIGNIFICANCE

It is now understood that testing subjects shod versus barefoot may lead to significantly different results. Clinically, measures such as dynamic postural stability are often used in the pre-test, post-test method to assess an individual's progression during treatment or following a procedure. Testing these individuals in varying footwear conditions pre-and post may result in different values only because of the change in footwear. With understanding of the effect of footwear, it is important to be consistent with an individual's footwear during testing. Based on the data, a 95% confidence interval is expressed as mean (95% CI: lower boundary, upper boundary): NDPS 0.3470 (0.335, 0.359), NDPBF 0.3295 (0.317, 0.342), RWDPS 0.3438 (0.331, 0.357), RWDPBF 0.3365 (0.326, 0.347). For future study in any of the specified conditions, a DPSI score outside of these boundaries may reflect deficiency in dynamic postural stability in a young, healthy, and active population.

5.7 FUTURE RESEARCH

Future research should continue to investigate the effect of footwear on dynamic postural stability tasks and determine an appropriate footwear recommendation. The results from this study indicate that footwear conditions are likely to significantly effect DPSI scores. This finding leads to the need for other testing procedures and protocols to be evaluated for differences in results based on footwear. If differences are found, a standardized footwear recommendation should be made for each procedure.

The DPSI has been shown to be a reliable measure for both the RWDP and the NDP.[1, 7] In both reliability studies, footwear conditions were not specified. Future research should investigate the reliability of both the RWDP and the NDP in the shod and barefoot condition.

5.8 CONCLUSIONS

Based on the current results, different protocols and footwear conditions result in different DPSI scores. Therefore, a standardized protocol and footwear condition should be established for each study. In order to accurately produce DPSI results that can be compared between participants, it is vital to utilize only one protocol and one footwear condition throughout testing. In order to accurately and meaningfully compare DPSI results across varying studies, it is vital that both studies collected DPSI data utilizing the same protocol and footwear condition.

It is believed that standardizing both the NDP and RWDP to a barefoot condition would be beneficial for data collection. The results reveal less difference in DPSI scores and more correlation between protocols when participants are in the barefoot condition. Participants should have one consistent DPSI score and this was identified in the barefoot condition.

We also conclude that the NDP may be more sensitive to changes in DPSI scores due to the significant difference between footwear conditions. This follows along with previous literature showing that footwear conditions significantly effect DPSI scores.[20, 21] In opposition of previous literature[34], no significant difference in DPSI scores was found between genders for any condition or protocol.

As seen in Table 5, footwear conditions within the NDP significantly affected the DPSI scores. Within the RWDP, no significant difference was found between footwear conditions but post hoc power analysis determined a low power ($\beta = 0.3979$). Had more participants been tested, the trending difference between RWPD footwear conditions DPSI scores may have become significant.

We conclude that the barefoot conditions results in lower DPSI scores due to the decrease in proprioceptive feedback in the shod condition[55] and the increase in forefoot striking in the barefoot condition.[56] We also conclude that the NDP and RWDP should be used as separate DPSI protocols and are not comparable. With the NDP showing a higher sensitivity to differences in footwear conditions and having an overall simpler protocol, we conclude that the NDP with the barefoot condition should be used as the standard “Schmitz protocol” for testing using the DPSI.

APPENDIX A

DEMOGRAPHIC AND DATA COLLECTION SHEETS

These sheets will be used to collect demographic data from participants prior to testing. The data includes age, gender, height, weight, maximum vertical jump, and all data collection information.

Figure 13. Data Collection Sheet

COMPARISON AND CORRELATION OF DYNAMIC POSTURAL STABILITY INDICES OBTAINED DURING DIFFERENT DYNAMIC LANDING TASKS AND FOOTWEAR CONDITIONS

PI: Joseph L. Schmitz
IRB#:

Subject ID:__________ **50% of Maximum Vertical Barefoot:**_________
50% of Maximum Vertical Shod:___________

Gender:_________

Limb Dominance:_______

40% of Height Shod:____________ **Type of Exercise:**______________
Time Wearing Shoes:_________________

40% of Height Barefoot:______________ **Shoe Brand and Style:**________________

Study Procedure	Performed Per Protocol and Documented	Y/N
Phone Screen:	Date:__________	
	Inclusion Criteria for Study	
	Given Instruction on Attire	
	Provided Directions to NMRL	

Comments:

Signature:

Test Session Date:__________

Anthropometrics	Weight Shod (kg):______Weight Barefoot (kg)______ Height Shod (mm):_______ Height Barefoot (mm):_______	
Dynamic Postural Stability Index	Maximum Vertical Jump Shod: **1.**____ **2.**____ **3.**____ Maximum Vertical Jump Barefoot: **1.**____ **2.**____ **3.**____ Practice Trials – NDP Shod: **1.** ____ **2.** ____ **3.** _____ Practice Trials – NDP Barefoot: **1.** ____ **2.** ____ **3.** _____ Practice Trials – RWDP Shod: **1.** ____ **2.** ____ **3.** _____ Practice Trials – RWDP Barefoot: **1.** ____ **2.** ____ **3.** _____ NDP Shod: **1.** ____ **2.** ____ **3.** ____ **4.**____ **5.**____ **6.**____ **7.**____ NDP Barefoot: **1.** ____ **2.** ____ **3.** ____ **4.**____ **5.**____ **6.**____ **7.**____ RWDP Shod: **1.** ____ **2.** ____ **3.** ____ **4.**____ **5.**____ **6.**____ **7.**____ RWDP Barefoot: **1.** ____ **2.** ____ **3.** ____ **4.**____ **5.**____ **6.**____ **7.**____	

Test Termination	Collect any used equipment	
	Pay the subject	

Adverse Events:

Additional comments/concerns:

Signature: ______________________________

Figure 14. Sports Activity Rating Scale

TABLE 1. Sports Activity Rating Scale

	Points	*Sports*
Level I		
4–7 days/week	100	Jumping, hard pivoting, cutting (basketball, volleyball, football, soccer, gymnastics)
	95	Running, twisting, turning (racquet sports, baseball, hockey, skiing, wrestling)
	90	No running, twisting, jumping (running, cycling, swimming)
Level II		
1–3 days/week	85	Jumping, hard pivoting, cutting (basketball, volleyball, football, soccer, gymnastics)
	80	Running, twisting, turning (racquet sports, baseball, hockey, skiing, wrestling)
	75	No running, twisting, jumping (running, cycling, swimming)
Level III		
1–3 times/month	65	Jumping, hard pivoting, cutting (basketball, volleyball, football, soccer, gymnastics)
	60	Running, twisting, turning (racquet sports, baseball, hockey, skiing, wrestling)
	55	No running, twisting, jumping (running, cycling, swimming)
Level IV		
No sports possible	40	ADL with no problems
	20	ADL with moderate problems
	0	ADL with severe problems

Figure 15. Cumberland Ankle Instability Questionnaire

Please tick the ONE statement in EACH question that BEST describes your ankles.

	LEFT	RIGHT	SCORE
1. I have pain in my ankle			
Never	☐	☐	5
During sport	☐	☐	4
Running on uneven surfaces	☐	☐	3
Running on level surfaces	☐	☐	2
Walking on uneven surfaces	☐	☐	1
Walking on level surfaces	☐	☐	0
2. My ankle feels UNSTABLE			
Never	☐	☐	4
Sometimes during sport (not every time)	☐	☐	3
Frequently during sport (every time)	☐	☐	2
Sometimes during daily activity	☐	☐	1
Frequently during daily activity	☐	☐	0
3. When I make SHARP turns, my ankle feels UNSTABLE			
Never	☐	☐	3
Sometimes when running	☐	☐	2
Often when running	☐	☐	1
When walking	☐	☐	0
4. When going down the stairs, my ankle feels UNSTABLE			
Never	☐	☐	3
If I go fast	☐	☐	2
Occasionally	☐	☐	1
Always	☐	☐	0
5. My ankle feels UNSTBLE when standing on ONE leg			
Never	☐	☐	2
On the ball of my foot	☐	☐	1
With my foot flat	☐	☐	0
6. My ankle feels UNSTABLE when			
Never	☐	☐	3
I hop from side to side	☐	☐	2
I hop on the spot	☐	☐	1
When I jump	☐	☐	0
7. My ankle feels UNSTABLE when			
Never	☐	☐	4
I run on uneven surfaces	☐	☐	3
I jog on uneven surfaces	☐	☐	2
I walk on uneven surfaces	☐	☐	1
I walk on a flat surface	☐	☐	0
8. TYPICALLY, when I start to roll over (or twist) on my ankle, I can stop			
Immediately	☐	☐	4
Often	☐	☐	3
Sometimes	☐	☐	2
Never	☐	☐	1
I have never rolled over on my ankle	☐	☐	0
9. After a TYPICAL incident of my ankle rolling over, my ankle returns to "normal "			
Almost immediately	☐	☐	4
Less than one day	☐	☐	3
1-2 days	☐	☐	2
More than 2 days	☐	☐	1
I have never rolled over on my ankle	☐	☐	0

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