Validity and inter-rater reliability of ankle motion observed during a single leg squat

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ABSTRACT

Background. The single leg squat (SLS) test is a clinical functional test commonly used to evaluate clinically aberrant movement patterns of the knee. The SLS could be an interesting option to analyze ankle control in the frontal plane during dynamic load analysis. However, to date, there are no studies that have analyzed the associations between the increased subtalar joint pronation by navicular drop (ND) test and ankle control with single leg squat (SLSankle) using a three-point scale. The purpose of this study was to evaluate the reliability of a clinical observation method to assess and determine the relationship between navicular drop (ND) and ankle control on the SLSankle score.

Methods. A total of fifty-five healthy, physically active (31 females and 24 males) volunteers participated in this study. The degree of subtalar pronation was assessed through the ND test, and the ankle control was defined as the ankle displacement in the frontal plane during the SLS.

Results. We found good intra-rater and inter-rater agreement during SLSankle, with Kappa values from 0.731 to 0.750. The relationship between the SLSankle and ND was significant; the Spearman’s rank correlation coefficient was 0.504 (p < 0.05).

Conclusions. The SLSankle Score supplied the clinical practice with a reliable and valid alternative for quantifying foot mobility in comparison to the ND test.

INTRODUCTION

The single leg squat (SLS) test is a clinical functional test commonly used to evaluate movement patterns of the lower limbs to assist clinicians with screening and diagnosis (Weeks, Carty & Horan, 2012). Visual observation movement screening tests offer an inexpensive, readily accessible, and easily applied assessment of the movement system in a clinical setting.

The SLS test is a tool to assess the risk of lower extremity injury (Ugalde et al., 2015), such as anterior cruciate ligament (ACL) injury (Yamazaki et al., 2010; Yokoyama et al., 2021), patellofemoral pain (Herrington, 2014; Gwynne & Curran, 2018), and non-arthritic hip pain (McGovern et al., 2020).
The movement patterns are used with visual rating scales (Harris-Hayes et al., 2014). The observer assesses the degree of medial–lateral knee motion during a single limb squat. Often, medial knee motion during the squat is indicative of hip abductor and/or external rotation muscle dysfunction (Ageberg et al., 2010; Crossley et al., 2011). Foot and ankle movement and mechanics, along with the hip musculature, may also have an impact on the kinematics of the lower extremity.

During closed-chain activities, restricted ankle dorsiflexion (DF) range of motion (ROM) is often accompanied by decreased sagittal plane motion of the knee, hip, and trunk, as well as increased frontal plane motion of the lower extremity (Bell, Padua & Clark, 2008). For example, during a squat, restricted DF ROM may result in excessive subtalar joint pronation and midtarsal dorsiflexion (Fong et al., 2011) tibial and femoral internal rotation, medial knee displacement, knee valgus (Macrum et al., 2012; Dill et al., 2014) and pelvis drop (Wilczyński, Zorena & Ślęzak, 2020). Decreased DF ROM was also associated with reduced quadriceps activation and increased soleus activity during the descent portion of a squat (Macrum et al., 2012). Thus, the ankle is important for evaluation during the single leg squat and plays as it has a stabilizing performance during the closed chain task (Warner et al., 2019).

The navicular drop (ND) test described by Brody (1982) is a clinical test used to evaluate rearfoot and midfoot pronation and assess the function of the medial longitudinal arch. The integrity of the medial longitudinal arch (MLA) is an important factor in kinematics and function of the lower extremities during weight bearing (Nilsson et al., 2012). ND is measured by recording the difference (in millimeters) between navicular tuberosity height in standing weight bearing and resting standing foot position (Shrader et al., 2005). Firstly, the subject was the sitting position with both knees in 90° flexion, with the foot on the floor and then the navicular tuberosity was palpated and marked. Clinical measures the distance from the navicular tuberosity to the floor. Secondly, the participant standing with weight equally distributed on both feet, clinician measures distance from the navicular tuberosity to the floor (Brody, 1982; Mulligan & Cook, 2013; Elataar et al., 2020; Allam et al., 2021).

The navicular drop test demonstrates excellent reliability, with intra-rater and inter-rater interclass correlation coefficient values ranging from 0.914 to 0.945 (Spörndly-Nees et al., 2011; Zuil-Escobar et al., 2018). An ND ≥ 10 mm is considered an excessive amount of foot pronation (Headlee et al., 2008). Furthermore, excessive pronation of the foot has been associated with increased risk of lower extremity injuries in military cadets (Levy et al., 2006) and athletes (Michelson, Durant & McFarland, 2002).

In contrast, dynamic weight-bearing task analysis is very important to reproduce activities of daily living. The SLS could be an interesting option to analyze ankle control in the frontal plane during dynamic load analysis. However, to date, there are no studies that have analyzed the associations between the increased subtalar joint pronation by ND test and ankle control with single leg squat (SLS ankles) using a three-point scale.

Therefore, the aims of this study were to (1) evaluate the reliability of a clinical observation method of assessment, and (2) determine the relation between the assessment
of ankle control during SLS\textsubscript{ankle} and the navicular test. We hypothesized that a higher ND score would correlate with the lateral malleolus displacement during the SLS.

**MATERIALS & METHODS**

An a priori power analysis was conducted to estimate the sample size. G*Power software (G*Power 3.1.9.6 Kiel University, Kiel, Germany) \textit{(Faul et al., 2007)} estimated a sample size of 34 subjects (significance level = 0.05; required power = 0.80; correlation among repeated measures = 0.30). A pilot study with 6 subject was used to estimate the sample size.

**Study design**

An observational study was performed between April and June 2019. The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the CyMO Research Institute (Valladolid, Spain: 1.200.553). All the participants read and signed an approved, written informed consent document before data collection.

**Participants**

Overall, fifty-five healthy, physically active adult volunteers, 31 females (21.3 ± 5.7 yrs., 163.5 ± 7.4 cm, 59.7 ± 7.7 kg) and 24 males (27.4 ± 12.7 yrs., 177.6 ± 7.9 cm, 76.8 ± 10.3 kg), were recruited for this study. All participants were healthy, reporting no injuries. Participants were excluded if they had any joint pathology in the hip, knee, or ankle that caused pain or restricted movement, neuromuscular disease, recent heel or knee pain, or a history of recent lower extremity trauma or elective surgery in the last six months.

**Procedures & measurements**

Participants completed three laboratory sessions in this study (one familiarization session and two test sessions) at one-week intervals. All sessions were performed at the same time of day to minimize the effect of circadian rhythms. All participants were instructed to refrain from exercising for 48 h prior to testing to reduce the potential influence of post-exercise muscle soreness or fatigue on performance in the SLS\textsubscript{ankle} test. During the testing session, participants carried out the following tests in a randomized order: the ND test and the SLS\textsubscript{ankle} test.

**Navicular drop**

Each subject was asked to stand barefoot, with weight distributed evenly over each foot. The navicular tuberosity was palpated and marked with a washable marker. With the subtalar joint in the neutral position, the distance between the navicular tuberosity and the floor was measured, in millimeters, with a caliper \textit{(Mulligan & Cook, 2013; Okamura et al., 2021)}.

The procedure was repeated three times for each participant. One measurement is subtracted from the other. In the cases in which this difference, expressed in millimeters, is \(\geq 10\) mm, the ND signifies an excessive pronation of the foot \textit{(Brody, 1982; Cote et al., 2005)}.
Single leg squat

The SLS was evaluated with the Leg MOtion® system (Leg Motion®, Check your Motion, Albacete, Spain) in a weight-bearing position. The Leg Motion® system (Check your Motion®, Albacete, Spain) is a valid portable, and easy to use alternative to the weight-bearing lunge test to assess ankle dorsiflexion ROM in healthy participants (Calatayud et al., 2015; Romero Morales et al., 2017; Moreno-Pérez et al., 2020). A digital camera (FDR-AX33, Sony, Tokyo, Japan) registered, through video recording, the lateral displacement of the ankle. The camera was placed on a tripod 3 m in front of the participant, at a height of approximately 0.9 m from the ground. This height was aligned approximately to the level of the participants’ pelvis. Video recording were made at 50 frames per second at a resolution of 1,920 × 1,080 pixels.

Participants stood barefoot with their feet shoulder-width apart, hips and knees extended, toes facing forward, and equal weight on both feet, and a marking strip made of masking tape (a rectangle with measures 30 × 10 millimeters) were applied to the skin over the lateral malleolus (Fig. 1).

Participants then placed one foot on the Leg MOtion platform with the second toe close to a corresponding starting line. Frontal plane ankle control was evaluated by visual observation (Junge et al., 2012) with a metal stick. A metal stick was placed along the line of the 2nd toe to indicate movement in the frontal plane during the SLS ank. Ankle control was defined as the ankle displacement in the frontal plane during the SLS ank.

Participants performed a SLS as far down as comfortably possible in four seconds (Nakagawa et al., 2012), keeping their trunk upright, their arms out to the side, and flexing their knee to at least 60° (Wyndow et al., 2016; Guillén-Rogel et al., 2021). In a previous study there are a consensus about the depth of the squat that a must be performed to at least 60° of knee flexion to be clinically rated as good (Crossley et al., 2011). Adequate knee flexion was visually confirmed by a researcher (Schmidt, Harris-Hayes & Salsich, 2019). Prior to testing, a researcher provided a visual demonstration of the test. Participants
performed 10 practice trials with each limb to become comfortable with the task. After a 3-minute rest, each participant performed five repetitions of the \( \text{SLS}_{\text{ankle}} \) test with each lower extremity, which was videotaped.

After a 15-day wash-out period (Streiner & Norman, 2008), two examiners (a physiotherapist and an athletic trainer) were sent the video recordings to assess the motion and rate the degree of ankle control. The examiners were trained to observe each video no more than two times without any pausing or slow motion, and each had more than 10 years of video-analysis experience. The sequence of the recording was randomized with a web-based research randomizer to minimize bias (Urbaniak & Plous, 2007).

Ankle control was scored using a three-point scale (0—good ankle control, 1—reduced and 2—poor) based on the distance from the metal stick to the lateral malleolus during the SLS movement (Fig. 1). A score of 0 was recorded when raters observed that the distance between the lateral malleolus and the metal stick was unchanged from the single leg standing to squatting position. A score of 1 was given when the raters observed that the distance from the lateral malleolus to the metal stick decreased from the single leg standing to squat position. A score of 2 was recorded when the marker on the lateral malleolus was aligned with the metal stick. The subjects were rated by their poorest test performance among the five trials.

**Statistical analysis**

Cohen’s kappa test was used to determine the intra-rater and inter-rater reliabilities. The kappa values were defined as poor if kappa was 0.20, fair for values of 0.21 to 0.40, moderate for 0.41 to 0.60, good for 0.61 to 0.80, and very good for 0.81 to 1.00 (Ashby, 1991).

One-way analysis of variance (ANOVA) was used to compare the ND test scores among the ankle control groups (good, reduced, or poor).

Spearman’s rank correlation coefficient was used to determine the correlation between the subjective assessment of ankle control with the scale of “good”, “reduced”, or “poor” and the ND test. All statistical analyses were conducted using SPSS (Version 22.0, IBM, Armonk, NY, USA). Effect sizes \( d \) were analyzed to determine the magnitude of an effect independent of sample size (the difference between the means divided by the pooled SD). A score of 0.5 and below was considered a low \( d \), 0.51–0.8 considered a medium \( d \), and 0.81 and above a large \( d \) (Cohen, 2013). Statistical significance was established at \( p < 0.05 \).

**RESULTS**

**Intra-rater reliability for the ankle control assessment**

We found good agreement between the first and second test during \( \text{SLS}_{\text{ankle}} \), with kappa values of 0.750 for the right side and 0.731 for the left side.

**Inter-rater reliability for the ankle control assessment**

The kappa values for the agreement between raters were 0.744 for the right side and 0.732 for the left side.

ANOVA showed significant differences \( (p < 0.05) \) for the ND test among the all \( \text{SLS}_{\text{ankle}} \) scores (Fig. 2).
Additionally, the relationship between the ankle control during SLS\textsubscript{ankle} and ND tests were investigated using the Spearman’s rho correlation. The Spearman’s rank correlation coefficient was 0.504 \((p < 0.05)\).

**DISCUSSION**

The aim of this study was to evaluate the reliability of a clinical observation method to assess and determine the relationship between navicular drop (ND) and ankle control on the single leg squat ankle score (SLS\textsubscript{ankle}). We found good intra-rater and inter-rater agreement during SLS\textsubscript{ankle}. The results determined that a higher ND score was correlated with lateral malleolus displacement during the SLS.

This study compared the reliability of a physiotherapy rater and athletic trainer rater; therefore, the experience level of these examiners is more likely to be an indicator of reliability \((Weeks, Carty \& Horan, 2012)\). Nevertheless, Tate \textit{et al.} \textit{(2015)} indicate excellent expert and novice test–retest reliability in measuring the frontal plane knee alignment during SLS.

Two-dimensional measurements of a lower extremity during a SLS, such as the frontal plane projection angle and visual evaluation, is suggested to be more cost effective and can easily be conducted in clinical settings as an alternative to three-dimensional motion capture \((Hansen, Lundgaard-Nielsen \& Henriksen, 2021)\). We found good intra- and inter-rater agreement for SLS\textsubscript{ankle} score. Similarly, Stensrud \textit{et al.} \textit{(2011)} conducted an assessment
using a two-dimensional video analysis during SLS in healthy participants and established excellent inter-rater reliability.

Various scoring systems have been used to assess dynamic alignment in the literature. Ressman, Grooten & Rasmussen Barr (2019) found that the analysis scales with a ≤ three-point rating scale show a higher inter-rater reliability compared with ≥ four-point rating scales of visual assessment of movement in the SLS test. However, there are no previous studies that have analyzed ankle control during a SLS using a three-point scale. The SLS\textsubscript{ankle} score shows the visual assessment scores of good, reduced, and poor on a three-point scale. However, Perrott et al. (2012) conducted analysis of foot alignment with a two-point scale (good and poor). The primary differences between the current study and Perrott et al. (2012) and Perrott et al. (2021) were not related to the degree of pronation.

Foot pronation was described as a predictor of altered joint kinetics and injuries (Brund et al., 2017), such as medial stress syndrome (Hamstra-Wright, Bliven & Bay, 2015; Menéndez et al., 2020). In addition, the alteration of the MLA can influence the biomechanics of the lower extremities. Therefore, from an injury prevention perspective, it is important to assess the deficits in active foot stabilization during dynamic pronation (Tourillon, Gojanovic & Fourchet, 2019).

The clinical implications of the test resemble the conditions of daily life, require no expensive or advanced equipment, and the experienced examiners can conduct a reliable visual assessment of the frontal plane of the ankle during an SLS test. Therefore, the use of SLS\textsubscript{ankle} score is a simple screening tool that can reduce the need for health practitioners to conduct another test of pronation.

A clear strength of the test used in this study is that it is easy to use and quickly performed, which gives it strength as a clinical test where both time and reliable evaluation are essential for diagnostics. The SLS test can allow us to simultaneously make an overall assessment of the motor control of the ankle, knee, hip, and trunk. The Leg Motion® system provides a standardized device to perform the foot position during the SLS\textsubscript{ankle}. On the other hand, it should be noted that it may also be valid to conduct the evaluation using the malleoli instead of the navicular bone as a landmark (Kanai et al., 2020).

There are some limitations of the current study. Only healthy individuals were included, while participants with plantar heel pain or joint pathology in the hip, knee, or ankle that caused pain were excluded. Contrastingly, despite the potential benefits of using the ND test, another limitation of the study is the ND test only capable of measuring displacement in the sagittal plane, while the movement of the navicular takes place in all three planes simultaneously (Vinicombe, Raspovic & Menz, 2001). Therefore, the evaluation of pronation movement was conducted without three-dimensional analyses; however, we aimed exclusively at assessing the reliability of the test assessments.

**CONCLUSIONS**

The findings of this study reveal that ankle displacement is a reliable tool to assess a single leg squat. A poor rating on the SLS test is associated with higher pronation in the ND test. The SLS\textsubscript{ankle} score has demonstrated good inter-rater and intra-rater reliability for two examiners. Therefore, the ankle assessment should be considered during dynamic
assessment and supplies clinical practice with a valid alternative to quantify foot mobility in comparison to the ND test.

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**ADDITIONAL INFORMATION AND DECLARATIONS**

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**Competing Interests**

We have conflicts of interest to disclose. Pedro J. Marín patented the LegMotion® system (CheckyourMotion®, Albacete, Spain).

**Author Contributions**

- Paloma Guillén-Rogel and Cristina San Emeterio conceived and designed the experiments, performed the experiments, analyzed the data, authored or reviewed drafts of the paper, and approved the final draft.
- Pedro J. Marín conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.

**Human Ethics**

The following information was supplied relating to ethical approvals (i.e., approving body and any reference numbers):

CyMO Research Institute.

**Patent Disclosures**

The following patent dependencies were disclosed by the authors:

Leg Motion®, Check your Motion, Albacete, Spain.

**Data Availability**

The following information was supplied regarding data availability:

The raw measurements are available in the Supplementary File.

**Supplemental Information**

Supplemental information for this article can be found online at [http://dx.doi.org/10.7717/peerj.12990#supplemental-information](http://dx.doi.org/10.7717/peerj.12990#supplemental-information).

**REFERENCES**

Ageberg E, Bennell KL, Hunt MA, Simic M, Roos EM, Creaby MW. 2010. Validity and inter-rater reliability of medio-lateral knee motion observed during a single-limb mini squat. *BMC Musculoskeletal Disorders* **11**:265  
DOI 10.1186/1471-2474-11-265.
Allam HH, Muhsen A, Al-walah MA, Alotaibi AN, Alotaibi SS, Elsayyad LK. 2021. Effects of plyometric exercises versus flatfoot corrective exercises on postural control and foot posture in obese children with a flexible flatfoot. *Applied Bionics and Biomechanics* 2021:Article 3635660 DOI 10.1155/2021/3635660.

Ashby D. 1991. Practical statistics for medical research. Douglas G. Altman, Chapman and Hall, London. *Statistics in Medicine* 10:1635–1636 DOI 10.1002/sim.4780101015.

Bell DR, Padua DA, Clark MA. 2008. Muscle strength and flexibility characteristics of people displaying excessive medial knee displacement. *Archives of Physical Medicine and Rehabilitation* 89:1323–1328 DOI 10.1016/j.apmr.2007.11.048.

Brody DM. 1982. Techniques in the evaluation and treatment of the injured runner. *The Orthopedic Clinics of North America* 13:541–558 DOI 10.1016/S0030-5898(20)30252-2.

Brund RBK, Rasmussen S, Nielsen RO, Kersting UG, Laessoe U, Voigt M. 2017. Medial shoe-ground pressure and specific running injuries: a 1-year prospective cohort study. *Journal of Science and Medicine in Sport* 20:830–834 DOI 10.1016/j.jsams.2017.04.001.

Calatayud J, Martin F, Gargallo P, García-Redondo J, Colado JC, Marín PJ. 2015. The validity and reliability of a new instrumented device for measuring ankle dorsiflexion range of motion. *International Journal of Sports Physical Therapy* 10:197–202.

Cohen J. 2013. *Statistical power analysis for the behavioral sciences*. New York: Routledge DOI 10.4324/9780203771587.

Cote KP, Brunet ME, Gansneder BM, Shultz SJ. 2005. Effects of pronated and supinated foot postures on static and dynamic postural stability. *Journal of Athletic Training* 40:41–46.

Crossley KM, Zhang W-J, Schache AG, Bryant A, Cowan SM. 2011. Performance on the single-leg squat task indicates hip abductor muscle function. *The American Journal of Sports Medicine* 39:866–873 DOI 10.1177/0363546510395456.

Dill KE, Begalle RL, Frank BS, Zinder SM, Padua DA. 2014. Altered knee and ankle kinematics during squatting in those with limited weight-bearing–lunge ankle–dorsiflexion range of motion. *Journal of Athletic Training* 49:723–732 DOI 10.4085/1062-6050-49.3.29.

Elataar FF, Abdelmajeed SF, Abdellatif NMN, Mohammed MM. 2020. Core muscles’ endurance in flexible flatfeet: a cross-sectional study. *Journal of Musculoskeletal & Neuronal Interactions* 20:404–410.

Faul F, Erdfelder E, Lang A-G, Buchner A. 2007. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods* 39:175–191 DOI 10.3758/BF03193146.

Fong C-M, Blackburn JT, Norcross MF, McGrath M, Padua DA. 2011. Ankle-dorsiflexion range of motion and landing biomechanics. *Journal of Athletic Training* 46:5–10 DOI 10.4085/1062-6050-46.1.5.

Guillén-Rogel P, Barbado D, Franco-Escudero C, San Emeterio C, Marín PJ. 2021. Are core stability tests related to single leg squat performance in active females?
Gwynne CR, Curran SA. 2018. Two-dimensional frontal plane projection angle can identify subgroups of patellofemoral pain patients who demonstrate dynamic knee valgus. Clinical Biomechanics 58:44–48 DOI 10.1016/j.clinbiomech.2018.06.021.

Hamstra-Wright KL, Bliven KCH, Bay C. 2015. Risk factors for medial tibial stress syndrome in physically active individuals such as runners and military personnel: a systematic review and meta-analysis. British Journal of Sports Medicine 49:362–369 DOI 10.1136/bjsports-2014-093462.

Hansen R, Lundgaard-Nielsen M, Henriksen M. 2021. Visual assessment of dynamic knee joint alignment in patients with patellofemoral pain: an agreement study. PeerJ 9:e12203 DOI 10.7717/peerj.12203.

Harris-Hayes M, Steger-May K, Koh C, Royer NK, Graci V, Salsich GB. 2014. Classification of lower extremity movement patterns based on visual assessment: reliability and correlation with 2-dimensional video analysis. Journal of Athletic Training 49:304–310 DOI 10.4085/1062-6050-49.2.21.

Headlee DL, Leonard JL, Hart JM, Ingersoll CD, Hertel J. 2008. Fatigue of the plantar intrinsic foot muscles increases navicular drop. Journal of Electromyography and Kinesiology 18:420–425 DOI 10.1016/j.jelekin.2006.11.004.

Herrington L. 2014. Knee valgus angle during single leg squat and landing in patellofemoral pain patients and controls. The Knee 21:514–517 DOI 10.1016/j.knee.2013.11.011.

Junge T, Balsnes S, Runge L, Juul-Kristensen B, Wedderkopp N. 2012. Single leg mini squat: an inter-tester reproducibility study of children in the age of 9–10 and 12–14 years presented by various methods of kappa calculation. BMC Musculoskeletal Disorders 13:203 DOI 10.1186/1471-2474-13-203.

Kanai Y, Mutsuzaki H, Watanabe M, Takeuchi R, Mатаki Y, Endo Y, Yozu A. 2020. Use of malleoli as an indicator for flatfoot in patients with Down syndrome: development of a simple and non-invasive evaluation method through medial longitudinal arch. Journal of Physical Therapy Science 32:315–318 DOI 10.1589/jpts.32.315.

Levy JC, Mizel MS, Wilson LS, Fox W, McHale K, Taylor DC, Temple HT. 2006. Incidence of foot and ankle injuries in west point cadets with pes planus compared to the general cadet population. Foot & Ankle International 27:1060–1064 DOI 10.1177/107110070602701211.

Macrum E, Bell DR, Boling M, Lewek M, Padua D. 2012. Effect of limiting ankle-dorsiflexion range of motion on lower extremity kinematics and muscle-activation patterns during a squat. Journal of Sport Rehabilitation 21:144–150 DOI 10.1123/jsr.21.2.144.

McGovern RP, Martin RL, Phelps AL, Kivlan BR, Nickel B, Christoforetti JJ. 2020. Conservative management acutely improves functional movement and clinical outcomes in patients with pre-arthritis hip pain. Journal of Hip Preservation Surgery 7:95–102 DOI 10.1093/jhps/hnz075.
Menéndez C, Batalla L, Prieto A, MÁ Rodríguez, Crespo I, Olmedillas H. 2020. Medial tibial stress syndrome in novice and recreational runners: a systematic review. *International Journal of Environmental Research and Public Health* **17**:7457 DOI 10.3390/ijerph17207457.

Michelson JD, Durant DM, McFarland E. 2002. The injury risk associated with pes planus in athletes. *Foot & Ankle International* **23**:629–633 DOI 10.1177/107110070202300708.

Moreno-Pérez V, Del Coso J, Raya-González J, Nakamura FY, Castillo D. 2020. Effects of basketball match-play on ankle dorsiflexion range of motion and vertical jump performance in semi-professional players. *The Journal of Sports Medicine and Physical Fitness* **60**(1):110–118 DOI 10.23736/S0022-4707.19.09918-3.

Mulligan EP, Cook PG. 2013. Effect of plantar intrinsic muscle training on medial longitudinal arch morphology and dynamic function. *Manual Therapy* **18**:425–430 DOI 10.1016/j.math.2013.02.007.

Nakagawa TH, Moriya ET, Maciel CD, Serrão FV. 2012. Trunk, pelvis, hip, and knee kinematics, hip strength, and gluteal muscle activation during a single-leg squat in males and females with and without patellofemoral pain syndrome. *Journal of Orthopaedic & Sports Physical Therapy* **42**:491–501 DOI 10.2519/jospt.2012.3987.

Nilsson MK, Friis R, Michaelsen MS, Jakobsen PA, Nielsen RO. 2012. Classification of the height and flexibility of the medial longitudinal arch of the foot. *Journal of Foot and Ankle Research* **5**:3 DOI 10.1186/1757-1146-5-3.

Okamura K, Egawa K, Ikeda T, Fukuda K, Kanai S. 2021. Relationship between foot muscle morphology and severity of pronated foot deformity and foot kinematics during gait: a preliminary study. *Gait & Posture* **86**:273–277 DOI 10.1016/j.gaitpost.2021.03.034.

Perrott MA, Pizzari T, Opar M, Cook J. 2012. Development of clinical rating criteria for tests of lumbopelvic stability. *Rehabilitation Research and Practice* **2012**:1–7 DOI 10.1155/2012/803637.

Perrott MA, Pizzari T, Opar MS, Cook J. 2021. Athletes with a clinical rating of good and poor lumbopelvic stability have different kinematic variables during single leg squat and dip test. *Physiotherapy Theory and Practice* **37**:906–915 DOI 10.1080/09593985.2019.1655823.

Ressman J, Grooten WJA, Rasmussen Barr E. 2019. Visual assessment of movement quality in the single leg squat test: a review and meta-analysis of inter-rater and intrarater reliability. *BMJ Open Sport & Exercise Medicine* **5**:e000541 DOI 10.1136/bmjsem-2019-000541.

Romero Morales C, Calvo Lobo C, Rodríguez Sanz D, Sanz Corbalán I, Ruiz Ruiz BB, López López D. 2017. The concurrent validity and reliability of the Leg Motion system for measuring ankle dorsiflexion range of motion in older adults. *PeerJ* **5**:e2820 DOI 10.7717/peerj.2820.

Schmidt E, Harris-Hayes M, Salsich GB. 2019. Dynamic knee valgus kinematics and their relationship to pain in women with patellofemoral pain compared to...
women with chronic hip joint pain. *Journal of Sport and Health Science* 8:486–493 DOI 10.1016/j.jshs.2017.08.001.

**Shrader JA, Popovich JM, Gracey GC, Danoff JV. 2005.** Navicular drop measurement in people with rheumatoid arthritis: interrater and intrarater reliability. *Physical Therapy* 85:656–664 DOI 10.1093/ptj/85.7.656.

**Spörndly-Nees S, Dåsberg B, Nielsen RO, Boesen MI, Langberg H. 2011.** The navicular position test—a reliable measure of the navicular bone position during rest and loading. *International Journal of Sports Physical Therapy* 6:199–205.

**Stensrud S, Myklebust G, Kristianslund E, Bahr R, Krosshaug T. 2011.** Correlation between two-dimensional video analysis and subjective assessment in evaluating knee control among elite female team handball players. *British Journal of Sports Medicine* 45:589–595 DOI 10.1136/bjsm.2010.078287.

**Streiner DL, Norman GR. 2008.** Biases in responding. In: *Health measurement scales*. Oxford: Oxford University Press, 103–134 DOI 10.1093/acprof:oso/9780199231881.003.0006.

**Tate J, True H, Dale B, Baker C. 2015.** Expert versus novice interrater and intrarater reliability of the frontal plane projection angle during a single-leg squat. *International Journal of Athletic Therapy and Training* 20:23–27 DOI 10.1123/ijatt.2014-0116.

**Tourillon R, Gojanovic B, Fourchet F. 2019.** How to evaluate and improve foot strength in athletes: an update. *Frontiers in Sports and Active Living* 1:46 DOI 10.3389/fspor.2019.00046.

**Ugalde V, Brockman C, Bailowitz Z, Pollard CD. 2015.** Single leg squat test and its relationship to dynamic knee valgus and injury risk screening. *PM & R* 7:229–235 DOI 10.1016/j.pmrj.2014.08.361.

**Urbaniak GC, Plous S. 2007.** Research randomizer (version 4.0) [computer software].

**Vinicombe A, Raspovic A, Menz HB. 2001.** Reliability of navicular displacement measurement as a clinical indicator of foot posture. *Journal of the American Podiatric Medical Association* 91:262–268 DOI 10.7547/87507315-91-5-262.

**Warner MB, Wilson DA, Herrington L, Dixon S, Power C, Jones R, Heller MO, Carden P, Lewis CL. 2019.** A systematic review of the discriminating biomechanical parameters during the single leg squat. *Physical Therapy in Sport* 36:78–91 DOI 10.1016/j.ptsp.2019.01.007.

**Weeks BK, Carty CP, Horan SA. 2012.** Kinematic predictors of single-leg squat performance: a comparison of experienced physiotherapists and student physiotherapists. *BMC Musculoskeletal Disorders* 13:207 DOI 10.1186/1471-2474-13-207.

**Wilczyński B, Zorena K, Ślężak D. 2020.** Dynamic knee valgus in single-leg movement tasks. Potentially modifiable factors and exercise training options. A Literature Review. *International Journal of Environmental Research and Public Health* 17:8208 DOI 10.3390/ijerph17218208.

**Wyndow N, De Jong A, Rial K, Tucker K, Collins N, Vicenzino B, Russell T, Crossley K. 2016.** The relationship of foot and ankle mobility to the frontal plane projection angle in asymptomatic adults. *Journal of Foot and Ankle Research* 9:3 DOI 10.1186/s13047-016-0134-9.
Yamazaki J, Muneta T, Ju YJ, Sekiya I. 2010. Differences in kinematics of single leg squatting between anterior cruciate ligament-injured patients and healthy controls. *Knee Surgery, Sports Traumatology, Arthroscopy* 18:56–63 DOI 10.1007/s00167-009-0892-z.

Yokoyama S, Fukuda W, Ikeno Y, Kataoka Y, Horan SA. 2021. Lower limb kinematics of single-leg squat performance in patients with anterior cruciate ligament deficiency. *Journal of Physical Therapy Science* 33:429–433 DOI 10.1589/jpts.33.429.

Zuil-Escobar JC, Martínez-Cepa CB, Martín-Urrialde JA, Gómez-Conesa A. 2018. Medial longitudinal arch: accuracy, reliability, and correlation between navicular drop test and footprint parameters. *Journal of Manipulative and Physiological Therapeutics* 41:672–679 DOI 10.1016/j.jmpt.2018.04.001.