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Relationship Between 3 Single-Leg Functional Performance Tests for Netball Noncontact Knee Injury Prevention Screening in Uninjured Female Adult Players

Nicholas C. Clark and Elaine M. Mullally

Context: Single- versus double-leg landing events occur the majority of the time in a netball match. Landings are involved in large proportions of netball noncontact knee injury events. Of all landing-induced anterior cruciate ligament injuries, most occur during single-leg landings. Knowledge of whether different single-leg functional performance tests capture the same or different aspects of lower-limb motor performance will therefore inform clinicians' reasoning processes and assist in netball noncontact knee injury prevention screening. ***Objective:*** To determine the correlation between the triple hop for distance (THD), single hop for distance (SHD), and vertical hop (VH) for the right and left lower limbs in adult female netball players. ***Design:*** Cross-sectional. ***Setting:*** Local community netball club. ***Participants:*** A total of 23 players (age 28.7 [6.2] y; height 171.6 [7.0] cm; mass 68.2 [9.8] kg). ***Interventions:*** There were 3 measured trials (right and left) for THD, SHD, and VH, respectively. ***Main Outcome Measures:*** Mean hop distance (percentage of leg length [%LL]), Pearson intertest correlation (r), and coefficient of determination (r^2). ***Results:*** Values (right and left; mean [SD]) were as follows: THD, 508.5 (71.8) %LL and 510.9 (56.7) %LL; SHD, 183.4 (24.6) %LL and 183.0 (21.5) %LL; and VH, 21.3 (5.2) %LL and 20.6 (5.0) %LL. All correlations were significant ($P \leq .05$), r/r^2 values (right and left) were THD–SHD, .91/.83 and .87/.76; THD–VH, .59/.35 and .51/.26; and SHD–VH, .50/.25 and .37/.17. A very large proportion of variance (76%–83%) was shared between the THD and SHD. A small proportion of variance was shared between the THD and VH (25%–35%) and SHD and VH (17%–25%). ***Conclusion:*** The THD and SHD capture highly similar aspects of lower-limb motor performance. In contrast, the VH captures aspects of lower-limb motor performance different to the THD or SHD. Either the THD or the SHD can be chosen for use within netball knee injury prevention screening protocols according to which is reasoned as most appropriate at a specific point in time. The VH, however, should be employed consistently alongside rather than in place of the THD or SHD.

Keywords: tibiofemoral joint, injury control, athlete assessment

Netball is a predominantly female team game with millions of players in 117 countries.[1] Netball was modified from women's basketball in the 1890s, was first played in England in 1895, and later became popular across the British Commonwealth.[2] In the United States, netball is a relatively young sport, which gained popularity in the 1980s.[3] More recently, the World University Netball Championships were hosted in Miami, FL, in 2016,[4] and the US Open Netball Championships attracted a record 100,000 Internet viewers in 2017.[3] Netball America now has members in 33 states[3] and a new high-performance development pathway following successes of the US University Netball team.[5] Community-level netball participation is expected to grow in the United States following netball's countrywide introduction to schools and community centers.[3] With increased sport participation, however, comes increased injury frequency.[6]

Knee injuries represent large proportions of netball lower-limb injuries.[7,8] Across netball studies, 50% to 76% of knee injuries are of a noncontact trauma nature.[7,9,10] Netball anterior cruciate ligament (ACL) and meniscus injuries occur with a frequency of 17.2% to 22.4% and 4.5% to 32.7%, respectively.[7,11] For ACL reconstruction, the incidence rate is higher in netball (188/100,000 participants) than in basketball (109/100,000 participants).[12] ACL and meniscus injuries result in significant physical disability,[13] premature retirement from netball,[14] and posttrauma osteoarthritis.[15] Given the growing participation in netball in America,[3] it is prudent for clinicians to consider knee primary injury prevention strategies with community-level players to mitigate the burden of injury for players, teams, and society. Netball is a fast-paced game involving change-of-direction running, jumping, leaping, hopping, and ball throwing/catching.[16,17] Single- versus double-leg landing events occur 58.5% to 67.1% of the time in netball matches,[18,19] and landings are involved in 27.1% to 73.8% of netball injury events.[9,20] For ACL injuries, 53.8% occur during single-leg landings, and 46.2% occur during double-leg landings.[10] Single-leg functional performance tests (FPTs), such as leap and hop tests, are construct valid[21,22] and ecologically valid[17,23] assessment tools relative to high-impact loading during single-leg landing tasks. Single-leg FPTs recreate the knee compression, shear, and torsion forces encountered in sport-specific activity[21,24] and are advocated to isolate each lower-limb and expose unilateral deficits that remain hidden in double-leg tasks.[21,25] Prospective research reported that adult athletes with a single hop for distance (SHD) mean distance of ≤64% of height had increased risk of thigh and knee injuries,[26] and adult athletes with a side-to-side difference (asymmetry) of >10% for the SHD experienced more frequent noncontact ankle and foot trauma.[27] In child and adolescent athletes, increased SHD performance was prospectively associated with decreased risk for traumatic knee injuries.[28] Single-leg FPTs are therefore an essential

Clark is with the School of Sport, Rehabilitation, and Exercise Sciences, University of Essex, Colchester, Essex, United Kingdom. Mullally is with the Faculty of Sport, Health and Applied Sciences, St Mary's University, Twickenham, United Kingdom. Clark (n.clark@essex.ac.uk) is corresponding author.

component of netball-specific knee primary injury prevention screening.

Primary injury prevention refers to the prevention of first-time injury and includes all countermeasures to eliminate or minimize injury occurrence.[29] Injury prevention does not expect the literal prevention of all injuries but the prevention of as many injuries as possible.[29] The practice of injury prevention screening is, therefore, a process to identify modifiable characteristics (risk factors) that increase players' probability for or predisposition to sustaining an injury.[30,31] Screening for modifiable injury risk factors at multiple time points across a season/year is advocated.[31–33] Repeated knee injury prevention screening is, subsequently, a diligent and sensible strategy in netball. When choosing single-leg FPTs for netball knee injury prevention screening, considerations include that some FPTs may be more suited to assessing lower-limb force production (eg, vertical hop [VH]) versus force absorption (eg, horizontal hop) ability.[21] Repeated single-leg hops such as the triple hop for distance[34] (THD), crossover hop for distance,[34] and adapted crossover hop for distance[22] may also be useful for adding greater repeated impact absorption and frontal and transverse plane challenges to the knee joint.[21,22] Knowledge of whether different single-leg FPTs capture the same or different aspects of lower-limb motor performance will inform clinicians' reasoning processes in netball noncontact knee injury prevention screening.[35–37]

The purpose of this study was to determine the correlation between the THD, SHD, and VH for the right and left lower-limbs in adult female netball players. It was hypothesized that there would be no strong correlation between tests for either lower limb. The present analysis supplements other observations within a larger community netball knee injury prevention project.[33] Although similar correlation analyses have been performed previously,[36–39] this analysis is original because no previous work has examined relationships between the THD, SHD, and VH for the right and left lower limbs of community-level adult netball players. The findings from this new analysis will be practically significant because they will support clinicians' choices for specific single-leg FPTs employed in netball noncontact knee injury prevention screening protocols.

Methods

Study Design

This was a preseason cross-sectional study performed at an English local community netball club.

Participants

An a priori power analysis was performed using G*Power.[40] To detect a correlation of .50 with a power of 0.80 and a one-sided alpha of .05, 23 participants were required. St Mary's University ethics approval was obtained. Participants were recruited from one community netball club using an e-mail invitation distributed by the club secretary to all adult players. All participants completed an informed consent document and a physical activity readiness questionnaire.

Inclusion criteria were female players aged 18–55 years participating in one or more netball training/matches per week and registered for unrestricted preseason training. In line with the netball national governing body guidelines,[41] "registered for unrestricted preseason training" included participants' self-declaration that they were not pregnant and required to self-disqualify to avoid risk of miscarriage or injury to an unborn child or to the player herself. Exclusion criteria were as follows: current lower-quadrant pain; time-loss lower-quadrant injury in the previous 2 months (ie, injury requiring withdrawal from one or more training/matches); any history of lumbar spine/hip/knee/ankle fracture or surgery; and any current neurological condition that affects sensorimotor processing at any level of the nervous system (eg, concussion). A total of 23 players volunteered and reported being uninjured and available for team selection (age 28.7 [6.2] y; height 171.6 [7.0] cm; mass 68.2 [9.8] kg). The club competed in the London and South East Regional League and the Surrey County League.

Procedures

Data collection occurred in one session at the club's outdoor training site (concrete netball court). Players were required to avoid fatiguing sports/exercise for 48 hours beforehand. Test order considered skill demands (high to low), cumulative muscle fatigue, and time efficiency. Data collection happened in station order format: anthropometry (height, mass, and leg length); shod THD; shod SHD; and shod VH. Leg order was arbitrarily selected as right then left by the lead tester, and this order was then maintained by all testers at subsequent stations. Players alternated between legs for each test. A standardized warm-up was performed by all players (toe walking, heel walking, parallel squats, forward lunge walk, right lateral-lunge walk, left lateral-lunge walk, high-knee lifts, butt kicks, right and left single-leg squats). Arm movement was allowed for all tests to assist balance.[42] Familiarization and practice trials for all tests were followed by 3 measured trials for each leg. Trials were discontinued if players reported any pain.

Standing height was measured[43] with a SECA 213 stadiometer (HaB Direct, Warwickshire, United Kingdom). Mass was measured[43] with SECA 760 weighing scales (HaB Direct). Leg length was measured[44] with a fiberglass anthropometric measuring tape (HaB Direct). Players were supine lying and barefoot on a portable treatment table with leg length measured once from the anterior superior iliac spine to the tip of the medial malleolus to the nearest millimeter.[44] Reliability (intraclass correlation coefficient [ICC] = .99) has been reported for this procedure.[44]

The THD[34] and SHD[34,45] were measured with a fiberglass athletics measuring tape (Sports Warehouse, Edinburgh, United Kingdom). For both tests, players stood on the test leg, the distal aspect of the foot aligned with the posterior edge of a taped start line (Figure 1) and the nontest leg comfortably flexed with the foot off the floor. For the THD,[34] players rapidly hopped forwards on the same leg 3 times (Figure 1) to stick the final landing for at least 2 seconds in a single-leg balanced position. For the SHD,[34,45] players hopped forwards on the same leg once (Figure 1) to stick the landing for at least 2 seconds in a single-leg balanced position. For both tests, the extent of a starting countermovement was self-selected.[37–39] For both tests, loss of balance and placing the opposite foot on the ground voided the trial and resulted in another attempt. Hop distance was measured from the posterior edge of the start line to the most distal aspect of the foot to the nearest 0.5 cm. Reliability has been reported for the THD (ICC = .95)[46] and SHD (ICC = .96).[46]

The VH was modified from previous work[47,48] and was recorded with a Panasonic HC-V720 high-definition Camcorder (Panasonic UK Ltd, Berkshire, United Kingdom) and analyzed using Kinovea freeware.[49] Players stood on the test leg with the nontest leg comfortably flexed and the foot off the floor. The video camera was flat on the floor, the front of the camera 30 cm from the

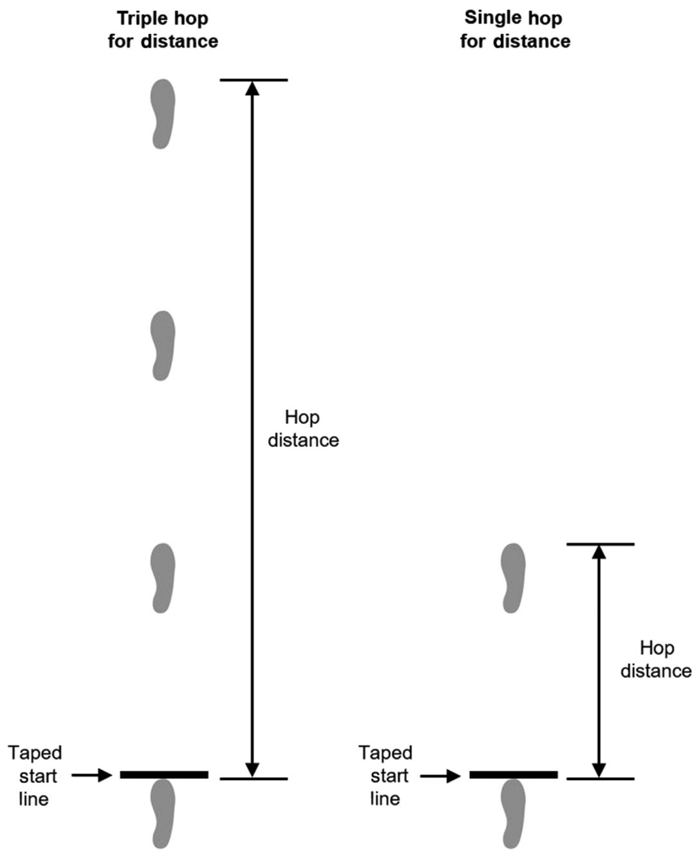

Figure 1 — Triple hop for distance and single hop for distance modified from reference 33.

lateral border of the foot and perpendicular to the midpoint of the foot's long axis. Players countermovement hopped upwards once as far as possible, straightening the leg (Figure 2), and then sticking the final landing for at least 2 seconds in a single-leg balanced position. If the test leg failed to straighten or the opposite foot touched down first, the trial was voided and another attempt performed. Players were given a "3, 2, 1, Go" countdown, and then a trial was performed. Camera recording started before the "Go" and stopped after the player had both feet on the ground. The camera was not moved during filming; players faced one direction for one leg and then turned to face the opposite direction for the other leg. Hop distance was calculated from flight time. Reliability for the calculation of distance from flight time has been reported (ICC = 1.00).[47]

Data Reduction

For the VH, video footage was loaded to a laptop computer with Kinovea freeware.[49] Test leg takeoff and landing were, respectively, defined as the first frame in which the foot was fully off the ground and any part of the foot was touching the ground.[47] The freeware's timer was used to calculate flight time (in seconds), and VH height was calculated using the formula $h = (t^2 \times 1.22625)$ where h is the height in meters and t is the flight time in seconds.[47] Hop height in meters was converted to centimeters. Normalization of data to leg length[50] was performed for all hop test trials: percentage leg length (%) = (distance hopped [cm] ÷ leg length [cm]) × 100. The mean normalized values for each leg within all hop tests were used for analyses.

Figure 2 — Vertical hop modified from reference 33.

Statistical Analyses

There were no missing data. Summary statistics were calculated including 95% confidence intervals. Normality of data was assessed using histogram inspection and Shapiro–Wilk tests. Between-test relationships were assessed with scatterplot inspection and Pearson correlation (r). Correlations were defined as moderate to strong (.50–.75) and strong to very strong (.75–1.00).[51] The proportion (in percentage) of variance shared between tests was assessed with the coefficient of determination (r^2).[23] An $r^2 \geq .60$ was employed as a threshold for defining a large proportion of shared variance and that hop tests captured highly similar aspects of lower-limb motor performance.[23,35] For all analyses, alpha was set a priori at .05.

Results

No player experienced pain during data collection, and there were no adverse events. Summary statistics are presented in the Table 1. All data were normally distributed. Example scatterplots for the right leg are presented in Figures 3–5. For some right and left leg scatterplots, outliers were evident in the lower or upper left quadrants; all relevant datapoints were reviewed, verified, and then retained. Correlations between the THD and SHD were right leg: $r = .91$, $r^2 = .83$, $P = .00$ and left leg: $r = .87$, $r^2 = .76$, $P = .00$. Correlations between the THD and VH were right leg: $r = .59$,

Table 1 Summary Statistics for Right and Left Normalized Hop Test Values (n = 23)

	Triple hop (%LL)		Single hop (%LL)		Vertical hop (%LL)	
Statistic	**R**	**L**	**R**	**L**	**R**	**L**
Min	383.4	427.6	131.9	133.0	8.5	6.5
Max	686.8	632.0	234.7	223.1	28.4	28.9
95% CI	477.5–539.5	486.4–535.4	172.7–194.0	173.7–192.4	19.0–23.5	18.4–22.3
Mean	508.5	510.9	183.4	183.0	21.3	20.6
SD	71.8	56.7	24.6	21.5	5.2	5.0

Abbreviations: %LL = percentage of leg length; R = right; L= left; Min = minimum; Max = maximum; 95% CI = 95% confidence interval (lower bound, upper bound); SD = standard deviation.

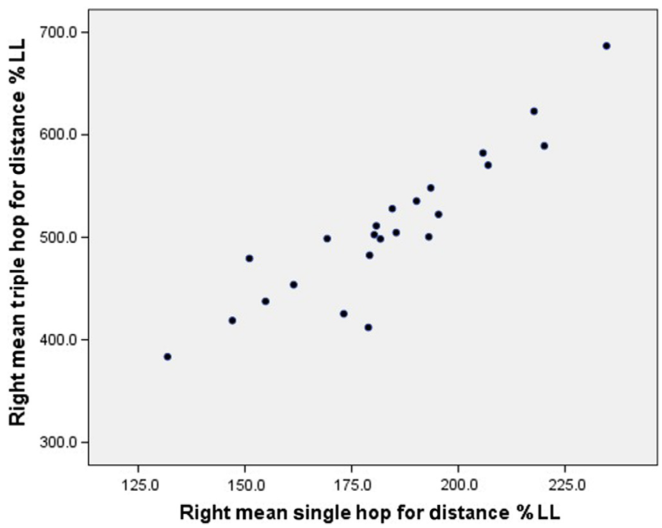

Figure 3 — Scatterplot for right mean single hop for distance versus right mean triple hop for distance. %LL indicates percentage of leg length.

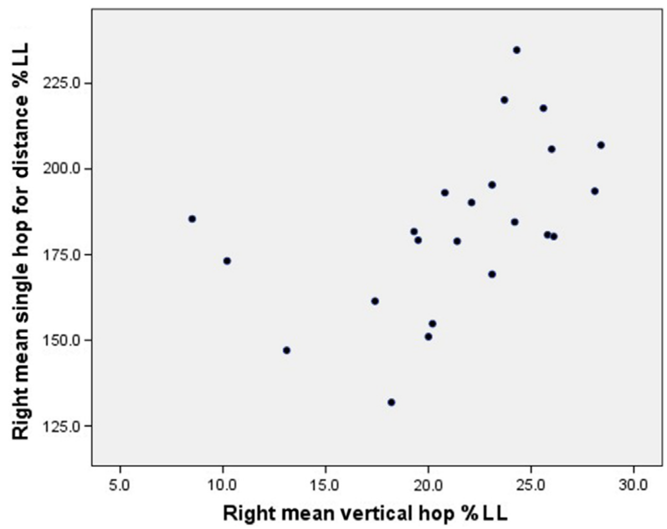

Figure 5 — Scatterplot for right mean vertical hop versus right mean single hop for distance. %LL indicates percentage of leg length.

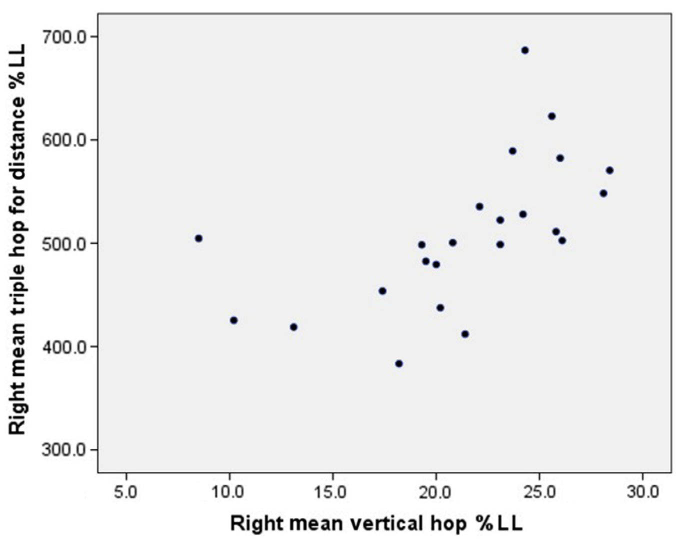

Figure 4 — Scatterplot for right mean vertical hop versus right mean triple hop for distance. %LL indicates percentage of leg length.

$r^2 = .35$, $P = .00$ and left leg: $r = .51$, $r^2 = .26$, $P = .01$. Correlations between the SHD and VH were right leg: $r = .50$, $r^2 = .25$, $P = .01$ and left leg: $r = .37$, $r^2 = .17$, $P = .05$. A very large proportion of variance (76%–83%) was shared between the THD and SHD across both legs. Up to a little over one third of the variance (26%–35%) was shared between the THD and VH across both legs. Up to one quarter of the variance (17%–25%) was shared between the SHD and VH across both legs.

Discussion

The purpose of this study was to determine the correlation between the THD, SHD, and VH for both lower-limbs in adult female netball players. It was hypothesized there would be no strong correlation between tests for either lower limb. Findings partially support the hypothesis as there was no strong correlation between the THD and VH or between the SHD and VH. However, there was a significant, positive, and very strong correlation between the THD and SHD with a very large proportion of variance shared between tests.

A direct comparison between the THD and SHD findings in this study and that of other work is not possible because no other group has performed such correlation analyses. One group, however, performed correlation analyses between a 10-m timed hop and the countermovement SHD and observed significant correlations for the dominant (Spearman Rho [r_s] = −.89, $P < .05$) and nondominant ($r_s = -.89$, $P < .05$) legs of a "healthy" mixed-sex cohort where the dominant leg was defined as the preferred kicking leg.[37] The size of such correlations are virtually identical to the size of the correlations observed in the present work for the THD versus the SHD. A direct comparison between the THD and VH findings in this study and that of other work is limited because only one other group has performed such correlation analyses. Hamilton et al[39] reported a significant and strong to very strong correlation ($r = .83$, $P < .05$) for the countermovement THD and VH in the dominant leg of a mixed-sex sample of university soccer players. The size of this correlation is substantially higher than that observed in the present work. In the previously cited study, correlation analyses between the 10-m timed hop and a countermovement VH yielded significant correlations for the dominant ($r_s = -.71$, $P < .05$) and nondominant ($r_s = -.63$, $P < .05$) legs.[37] The same study again examined the countermovement SHD and VH and once more reported significant correlations for the dominant ($r = .74$, $P < .05$) and nondominant ($r = .71$, $P < .05$) legs,[37] which are higher than the correlations observed for the right and left legs in the present work. In contrast, a number of groups have performed correlation analyses for the countermovement SHD and VH; these groups also performed dominant versus nondominant comparisons and permitted participants to land on 2 feet rather than one.[36,38] Maulder and Cronin[36] reported significant correlations between the SHD and VH for a male athlete data set that pooled the dominant and nondominant legs ($r = .79$, $P < .00$). Meylan et al[38] also reported significant correlations between the SHD and VH for dominant leg only data sets for male ($r = .64$, $P \le .01$) and female ($r = .66$, $P \le .01$) university physical education students. In other work that performed a correlation analysis for a noncountermovement SHD and VH in the dominant leg only, significant correlations have been reported for a mixed-sex group of adults ($r = .67$, $P < .00$)[52] and the previously mentioned cohort of male athletes ($r = .66$, $P < .00$).[36] Thus, when comparing and contrasting the present work with previous studies,[36–39,52] it seems that significant strong correlations (ie, $r \ge .75$, $P < .05$[51]) are consistently evident when a single-leg horizontal FPT is compared with another horizontal FPT but inconsistently evident when a single-leg horizontal FPT is compared with a vertical FPT; 2 studies observed significant and strong to very strong correlations between a single-leg horizontal FPT and vertical FPT,[36,39] whereas most (including this study) did not.[37,38,52] Such observations across studies imply that horizontal and vertical single-leg FPTs generally measure different aspects of lower-limb motor performance.[21,37]

Interpretation of the size and relevance of a correlation coefficient can alter according to differences in studies' contexts and sample sizes, and the coefficient of determination is useful for indicating the proportion (in percentage) of variance in one variable that is accounted for by another variable.[23,51] Together, correlation and the coefficient of determination are employed to examine whether one test captures similar or different aspects of lower-limb motor performance compared with another test.[35–37] Correlation between the THD and SHD was strong and significant for both legs, with a very large proportion of variance (76%–83%) shared between tests. Although consistently significant, correlation between the THD and VH, and the SHD and VH, were not strong for either leg. The present data therefore indicate the THD and SHD capture highly similar aspects of lower-limb motor performance. In contrast, the VH appears to capture aspects of lower-limb motor performance that are different to the THD or SHD. Subsequently, either the THD or the SHD can be chosen for use within netball knee injury prevention screening protocols according to which is reasoned as most appropriate at a specific point in time. For example, the SHD (one hop) is less demanding than the THD (3 hops); the SHD may be more appropriate for early preseason screening, whereas THD may be more appropriate for late preseason and in-season screening after players have completed a period of physical preparation training. The VH, however, should be employed consistently alongside rather than in place of the THD or SHD. In terms of real-world practical applications, use of the VH alongside the THD, for example, will then provide a more detailed profile of players' lower-limb motor performance than either the VH or the THD alone. Such a view is supported by other groups whose correlation analyses also resulted in recommendations for the use of a combination of horizontal and vertical single-leg FPTs.[36,37] Application of a battery of single-leg FPTs that capture different aspects of lower-limb motor performance will better inform clinicians' reasoning processes in netball noncontact knee injury prevention screening than any one single-leg FPT.

Knowledge of why horizontal and vertical single-leg FPTs capture different aspects of lower-limb motor performance is useful to inform clinicians' understanding further and validate reasoning practices.[21] According to sophisticated 3-dimensional biomechanical observation of double- and single-leg FPTs, different joints and muscle groups contribute different proportions to horizontal versus vertical athletic tasks. For horizontal FPT concentric phases, the hip, knee, and ankle extensors contribute a mean of 45.9%, 3.9%, and 50.2% to task execution, respectively.[53] For vertical FPT concentric phases, the hip, knee, and ankle extensors contribute a mean of 28%, 49%, and 23% to task execution, respectively.[54] For horizontal FPT eccentric phases, the hip extensors contribute a mean value 1.4 times that of the knee extensors.[55] For vertical FPT eccentric phases, the knee extensors contribute a mean value 3.7 times that of the ankle extensors.[56] Thus, horizontal FPTs generally involve larger contributions from the hip and ankle extensors, whereas vertical FPTs elicit a greater contribution from the knee extensors. Across studies, such biomechanical differences represent specific contrasts in motor programming and explain why horizontal versus vertical FPTs capture different aspects of lower-limb motor performance as determined using correlation analyses.

Potential limitations include not performing analyses using dominant/nondominant legs. Such analyses were not performed because dominance changes according to task demands (eg, load bearing vs skill).[57] Potential limitations also include not subgrouping players into different team positions. Such grouping was not performed because all netball players perform many different types of single-leg landing during a match.[17–19] Further potential limitations include not performing the present analyses with different grades/levels of player. Such analyses were not performed because most netball players worldwide compete at local community level,[1] and therefore, this study has substantial external validity[51] relative to the level of competition that most clinicians' players will aspire to. The findings of this study can only be generalized to uninjured female adult netball players competing with local community teams. Future research should replicate this study's design with child and adolescent netball players. Future research should also employ prospective designs to determine the effectiveness of the THD, SHD, and VH in noncontact knee injury prevention screening in uninjured female adult players.

Conclusion

The single-leg FPTs used in this study were safely employed with a community-level netball club. The THD and SHD were significantly and strongly correlated with a very large proportion of variance shared between tests. The THD and VH, and SHD and VH, were significantly and moderately correlated with only a small proportion of variance shared between tests. The THD and SHD therefore capture highly similar aspects of lower-limb motor performance. In contrast, the VH captures aspects of lower-limb motor performance different to the THD or SHD. Subsequently, either the THD or the SHD can be chosen for use within netball knee injury prevention screening protocols according to which is reasoned as most appropriate at a specific point in time. The VH, however, should be employed consistently alongside rather than in place of the THD or SHD. The new findings from this study will help support clinicians' choices for specific single-leg FPTs employed in netball noncontact knee injury prevention screening protocols.

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