The efficacy of lower limb screening tests in predicting PlayerLoad within a professional soccer academy

Abstract

Context: Training exposure has been associated with injury epidemiology in elite youth soccer, where lower limb musculoskeletal screening is commonly used to highlight injury risk. However, there has been little consideration of the relationship between lower limb screening and the loading response to soccer activities.

Objective: To quantify the efficacy of using screening tests to predict the loading elicited in soccer-specific activities, and to develop a hierarchical ordering of musculoskeletal screening tests to identify test redundancy and inform practice.

Design: Correlational.

Setting: Professional soccer club academy.

Participants: 21 elite male soccer players aged 15.7 ± 0.9 years.

Intervention: Players completed a battery of five screening tests (knee to wall, hip internal rotation, adductor squeeze, single leg hop, anterior reach), and a 25min standardised soccer session with a GPS unit placed at C7 to collect multi-planar PlayerLoad data.

Main Outcome Measures: Baseline data on each screening test, along with uni-axial PlayerLoad in the medio-lateral, anterio-posterior and vertical planes.

Results: Stepwise hierarchical modelling of the screening tests revealed that dominant leg knee to wall distance was the most prevalent and powerful predictor of multi-planar PlayerLoad, accounting for up to 42% of variation in uni-axial loading. The adductor squeeze test was the least powerful predictor of PlayerLoad. Of note, one player who incurred a knee injury within three weeks of testing had shown a 20% reduction in knee to wall distance compared with peers, and elicited 23% greater PlayerLoad, supporting the hierarchical model.

Conclusions: There was some evidence of redundancy in the screening battery, with implications for clinical choice. Hierarchical ordering and a concurrent case study highlight dominant leg knee to wall distance as the primary predictor of multi-axial loading in soccer. This has implications for the design and interpretation of screening data in elite youth soccer.

Soccer academies affiliated with professional clubs in England host age groups from as young as 6 years of age, with injury incidence tending to increase with age and up to 5 injuries per 1000 hrs of training and 20 injuries per 1000 hours of competition in players aged 13-18.[1] Injury prevalence in elite youth players has been shown to be higher than that observed in their senior peers, attributed to training exposure in young elite players who lack the skeletal maturity to tolerate the physical demands imposed.[2] Lower limb musculoskeletal abnormalities, malalignment and a reduced functional capacity in youth players may increase the risk of injury,[3,4] with a prevalence of lower limb injuries in youth soccer.[1,5]

The prevalence of injury and the subsequent impact on long-term player development in elite youth soccer warrants a consideration of prevention and monitoring strategies. Screening measures have been developed in order to monitor performance, highlight injury risk, and provide baseline measures,[6,7] but there is limited published research in elite adolescent soccer players.[6,7] There is also considerable diversity in the screening protocols used,[8,9] and their specific relevance to the demands of the sport and injury epidemiology.[10,11] In considering the validity of screening, the clinical tests used are often characterised by slow, controlled, predictive and low impact which lacks relevance to the demands imposed by training and competition demands.[12,13] However, this intuitive dissociation between clinical screening tests and the physical demands imposed by the sport might constrain clinical decision making. If the screening tests are able to predict the sport-specific physical response, then the efficacy in terms of injury monitoring and prevention would be clear.

Typically the predictive power of screening tests has been considered in relation to injury incidence, but recent developments in GPS technology enable the physical demands of training and competition to be quantified.[12,14] The performance metrics relating to distance and the derivatives including velocity have limited scope in a sport like soccer where the activity profile is self-paced, and the player dictates the activity profile to a large extent. Embedded technologies such as the accelerometer however enable a relatively high frequency and tri-axial consideration of acceleration, within an ecologically valid context and with implications for clinical interpretation.[15] A recent case study of a lateral ankle sprain in elite soccer highlighted loading in the medio-lateral plane during training and rehabilitation.[16] This planar loading data might have informed clinical decision making relating to the magnitude and asymmetry in loading, and the subsequent implications in injury management and return to play.[16]

Literature has therefore started to explore the potential association between injury risk and tri-axial accelerometry, but this has typically been performed retrospectively. In the current study we aim to employ a prospective research paradigm to consider the efficacy of clinical screening tests in predicting the multi-axial loading response to soccer-specific activity. We considered a range of commonly used screening tests, with our choice restricted to those tests that are used in soccer, have functional relevance, and have been previously considered in relation to statistical measures of reliability. In addition to considering each test in isolation, we aim to develop a hierarchical ordering of screening tests to examine redundancy in the testing battery and delimit toward those tests that offer greatest potential in predicting injury risk.

Methods

Design

We carried out the current study within an English professional soccer club academy. Testing was completed during the competitive season to provide an ecologically valid cross-sectional perspective, and to reduce the impact of seasonal fluctuations in performance and injury risk associated with the pre-season for example.[5]

Participants

All players were registered with the same professional soccer academy, standardising training volume amongst the group. Inclusion criteria required that each player was injury free at the time of testing, and was currently engaged in all elements of the prescribed training and competition load. A total of 21 male players (15.7±0.9 years, 176.2±5.2cm, 63.8±6.5 kg) completed the study, providing written informed consent in accordance with the departmental and university ethical procedures, and in accordance with the spirit of the Helsinki Declaration.

Procedures

All players had completed the screening battery on a minimum of three previous occasions as part of the normal practice of the academy medical staff. Consistent with club process, during the experimental trial all players received a standardised verbal instruction prior to each test. The tests (Figure 1) were conducted in standardised order and comprised: knee to wall test,[17] hip internal rotation test,[18] adductor squeeze test at 0, 45 and 90º,[19] single leg anterior reach,[20] and single leg hop for distance.[21]

** Insert Figure 1 near here **

These tests were selected based on their functional relevance, common use, and previous investigation of reliability.[17-21] Each test was conducted and scored according to published clinical guidelines, and using the dominant and non-dominant limb. Leg dominance was defined using the player's preferred kicking leg. A standardised starting state prior to testing was ensured by completion of a short warm up including: cycling on a static bike followed by dynamic stretches led by academy staff, and consistent with normal practice. Immediately following the completion of the screening battery, all players completed a standardised soccer-specific session. To attain a standardised activity profile, this session was developed around the design of the players' typical pre-match routine. Elements such as passive stretching were removed as these were tailored to individual needs, and resulted in skewed loading data. All players therefore completed the same activity profile comprising progressive intensity in running drills that incorporated speed and directional changes. The first 17mins of the session was completed without a soccer ball, with a strict demand on consistency across all players. The final 8mins of the session did include technical work with the ball, but again all elements were standardised across the groups. Small-sided games were not included given the potential variation in individual positional remits, and subsequently physical response. Consistent with club policy and normal practice, each player wore a MinimaxX S4 GPS unit (Catapult Innovations, Scoresby, Australia) located in a customised vest at a mid-scapula location approximating to C7. Tri-axial acceleration data was collected at 100Hz, and used to generate uni-axial measures of PlayerLoad based on the rate of change of acceleration.[15,22] Given the aims of the current study, the uni-axial measures of PlayerLoad (medio-lateral, anterio-posterior, vertical) were also sub-divided into directional indices, so as to consider medial and lateral for example. The medial:lateral imbalance was highlighted in a case study of injury in professional soccer.[16] This directional and planar response provides much richer information regarding movement quality,[16] and was considered appropriate given the focus on screening for injury risk.

Statistical Analyses

Each screening test performance measure was linearly correlated against each planar PlayerLoad response from the soccer session. Subsequently a forward stepwise hierarchical model of screening tests was developed for each PlayerLoad metric. The statistical model inputs at each stage the singular screening test measure which has the greatest linear correlation coefficient (r). The model is ceased when the addition of variables has no improvement on the correlation coefficient, thereby providing a hierarchical ordering of screening tests and a prescriptive battery. Tests not included in this model can thereby be considered redundant in the prediction of PlayerLoad. The degree of variation in PlayerLoad attributed to the screening test(s) was quantified as the square of the correlation coefficient r^2. This process was repeated for each plane, and in each direction (medial, lateral for example).

Results

Table 1 summarises squad demographics in terms of the clinical tests and the physical response to the soccer session. Table 2 then quantifies the r^2 value describing the linear correlation between each screening test and each directional PlayerLoad value. Cells are highlighted where there was a 'strong' correlation ($r \geq 0.6$), with dominant leg knee to wall distance most often providing the singular highest correlation with directional PlayerLoad. The highest single correlation was evident between dominant knee to wall distance and anterior loading, where 43% of variance is accounted for ($r = 0.66$).

** Insert Table 1 and Table 2 near here **

Table 3 summarises the hierarchical ordering of screening elements which predict directional PlayerLoad. The data is presented in steps, replicating the statistical model. Step 1 therefore describes the primary predictor and associated r^2 value; Step 2 describes the next most important predictor and is marked by an increased (though not summative) r^2; and so on until no additional variables are added (and r^2 increases no further). Across all directional and planar loading values, the screening battery was able to account for between 31% (lateral load) to 66% (downward load) of the variation in PlayerLoad.

** Insert Table 3 near here **

Dominant knee to wall distance was the most frequent (6) primary predictor of directional load, and the most frequent inclusion in the full hierarchical model (7). The hop task was also frequently included in the model (5 non-dominant, 4 dominant). The 90° adductor squeeze test was highlighted as being redundant, with no inclusion in the hierarchical ordering of PlayerLoad in any direction. Non-dominant reach and knee to wall distance, along with the adductor squeeze tests were represented only on a single occasion.

Discussion

Bahr (2016) recently highlighted the limited predictive value of clinical screening tests for injury, advocating research into other associated risk factors as part of periodic health examinations.[23] Our primary aims were to quantify the efficacy of using musculoskeletal screening tests to predict the loading elicited in soccer-specific activities, and to develop a hierarchical ordering of these screening tests to inform practice and identify test redundancy. An additional opportunity presented post-data collection enabling a clinical case study to be considered in relation to the established hierarchical ordering.

The single linear correlations between screening measures and PlayerLoad metrics revealed that the dominant leg knee to wall test was the strongest individual predictor of total PlayerLoad. This test was able to account for 39% of the variation in PlayerLoad accumulated during the soccer-specific session. This relationship can be attributed to strong correlations in the anterio-posterior and vertical planes, with dominant knee to wall distance accounting for 42% and 41% of the variability in respective planar loading. Conversely, only 10% of medio-lateral load was attributed to changes in knee to wall score. This directional specificity in correlation between the knee to wall test and planar loading reflects the linear nature of the ankle dorsiflexion task. The relationship between ankle dorsiflexion range and injury is equivocal,[24,25] but the association with PlayerLoad most likely reflects the activity patterns inherent in soccer. The intermittent nature of soccer results in an activity profile with an emphasis on stride frequency rather than stride length, since only with the foot in contact with the ground can a player initiate a change in speed or direction. The importance of mechanically efficient ground contact and gait is therefore likely to be enhanced by players with a greater degree of ankle dorsiflexion.

The importance of the dominant leg knee to wall distance in predicting PlayerLoad response to soccer-specific activity was further examined using a case study of a player involved in the study who subsequently suffered a dominant limb knee meniscal injury during training. This injury was sustained within three weeks of the data collection. Retrospective analysis revealed that this player reported a 20% reduction in dominant leg knee to wall distance compared with the mean of the other squad members. The player reported a 23% greater total PlayerLoad than the squad average, which was attributed to a 15% increase in medio-lateral load, a 28% increase in anterio-posterior load, and a 24% increase in vertical load during the same soccer-specific session.

Whilst conducted using retrospective analysis, this case study supports the hierarchical modelling output which suggests that the dominant leg knee to wall test might offer scope to highlight potential injury risk.

The single leg hop was frequently included in the hierarchical modelling of axial PlayerLoad, often representing the second step in the model. This test is commonly utilised as a predictor of sprint, jump and power based performance.[26] Test proficiency is frequently demonstrated to be lower in athletes with Anterior Cruciate Ligament reconstructions,[27] with hop distance included in a predictive model accounting for 56% of variance in total PlayerLoad.

The strong individual predictive power of the knee to wall test was highlighted in the hierarchical ordering applied across all screening measures used in the current study. The hierarchical models highlighted in Table 3 show that this screening battery was able to account for 56% of variation in total PlayerLoad, and up to 63% in vertical PlayerLoad. This observation is encouraging given the myriad of factors that can influence the biomechanical response to a soccer-specific activity session. Whilst the objective of the stepwise modelling approach is to highlight the primary predictive elements, this approach also serves to highlight test redundancy. The adductor squeeze test had little impact on the hierarchical models, despite previous research highlighting significantly lower performance in previously injured athletes.[7,28] Care should be taken to dissociate between injury incidence and the physical response to training load, and screening tests might be best used in association with injury history and training load data.

Hip internal rotation deficits are often associated with hip and groin symptoms,[29] and notably the non-dominant limb hip internal rotation score was the primary element in predicting total medio-lateral (and lateral) PlayerLoad. A reduction in hip internal rotation has been shown to influence lower limb biomechanics in the pivoting athlete, increasing susceptibility to Anterior Cruciate Ligament injury.[30] In the current study 31% of variance in lateral PlayerLoad was attributable to changes in hip internal rotation on the non-dominant side. Training sessions with greater emphasis on lateral movements might therefore elicit even greater association, and further endorse the predictive power of screening.

Based on frequency distribution, a reduced screen would include the knee-to-wall test and the single leg hop test. Given the influence of hip internal rotation on medio-lateral loading, this might also be included. This reduced testing battery would be capable of accounting for 56% of the variation in total PlayerLoad, 39% of medio-lateral load, 52% of anterio-posterior load, and 63% of vertical load. Care should be taken in generalising beyond the elite male youth soccer cohort, the screening tests, and activity session used in the current study. Further research might consider the use of athletes with previous injuries which have been closely aligned to screening tests to determine the sensitivity of accelerometry. The design of the activity session might also be aligned more specifically with clinical tasks, or with the planar nature of the PlayerLoad analysis. The current study considered a generic activity profile approximating a pre-competition warm-up whereas interpretation might be enhanced using specifically designed functional drills.

Conclusions

Dominant leg knee to wall distance was the most frequent and powerful predictor of multi-planar PlayerLoad. This single test was able to account for up to 42% of the variation in uni-axial loading, and a player who exhibited a 20% reduction in this test relative to his peers elicited 23% greater PlayerLoad and did subsequently incur a knee injury within three weeks of testing. Redundancy in screening was evident, with the adductor squeeze test the least powerful predictor of PlayerLoad. A reduced screening battery would include the knee to wall test, single leg hop test, and hip internal rotation.

References

1. Faude O, Robler R, Junge A. Football injuries in children and adolescent players: are there clues for prevention? *Sports Med.* 2013;43:819-837.
2. Pfirrmann D, Herbst M, Ingelfinger P, Simon P, Tug S. Analysis of injury incidences in male professional adult and elite youth soccer players: A systematic review. *J Athl Train.* 2016;51(5):410-424.
3. Kawlek K, Garsztka T. An analysis of muscle balance in professional field hockey players. *Trends Sports Sci.* 2013;4(20):181-187.
4. Sheerin KR, Hume PA, Whatman C. Effects of a lower limb functional exercise programme aimed at minimising knee valgus angle on running kinematics in young athletes. *Phys Ther Sport.* 2012;13:250-254.
5. Price RJ, Hawkins RD, Hulse MA, Hodson A. The Football Association Medical research programme: An audit of injuries in academy youth football. *Br J Sports Med.* 2004;38:466-471.
6. Dallinga JM, Benjaminse A, Kemmink KAPM. Which screening tools can predict injury to the lower extremities in team sports? *Sports Med.* 2012;42(9):791-815.
7. Nevin F, Delahunt E. Adductor squeeze test values and hip joint range of motion in Gaelic football athletes with longstanding groin pain. *J Sci Med Sport*. 2014;17(2):155-159.

8. Teyhen DS, Shaffer SW, Lorenson CL, Greenberg MD, Rogers SM, Koreerat CM, Villena SL, Walker MJ, Childs JD. Clinical measures associated with dynamic balance and functional movement. *J Strength Cond Res.* 2014;28(5):1272-1283.
9. McCall A, Carling C, Nedelec M, Davidson M, Gall F, Berthoin S, Dupont G. Risk factors, testing and preventative strategies for non-contact injuries in professional football: Current perceptions and practices of 44 teams from various premier leagues. *Br J Sports Med.* 2014;48:1352-1357.
10. Pacheco MM, Teixeira LAC, Franchini E, Takito MY. Functional vs. Strength training in adults: Specific needs define the best intervention. *Int J Sports Phys Ther.* 2013;18(1):34-43.
11. Miller A, Callister R. Reliable lower limb musculoskeletal profiling using easily operated, portable equipment. *Phys Ther Sport.* 2009;10(1):30-37.
12. Randers MB, Mujika I, Hewitt A, Santisteban J, Bischoff R, Solano R, Zubillaga A, Peltola E, Krustrup P, Mohr M. Application of four different football match analysis systems: A comparative study. *J Sports Sci.* 2010;28(2):171-182.
13. Aguiar MVD, Botelho GMA, Gonçalves BSV, Sampaio JE. Physiological responses and activity profiles of football small-sided games. *J Strength Cond Res.* 2013;27(5):1287-1294.
14. Akenhead R, Nassis GP. Training load and player monitoring in high-level football: Current practice and perceptions. *Int J Sports Physiol Perf.* 2016;11:587-593.
15. Greig M, Nagy P. Lumbar and cervicothoracic-spine loading during a fast-bowling spell. *J Sport Rehab.* 2017;26(4):257-262.
16. Brown W, Greig M. Tri-axial accelerometry as an injury predictor tool in elite soccer. *Int J Athl Train Ther.* 2017;22(5):44-48.

17. Cejudo A, Sainz De Baranda P, Ayala F, Santonja F. A simplified version of the weight-bearing ankle lunge test: description and test-retest reliability. *Manual Ther.* 2014;19:355-359.
18. Malliaras P, Hogan A, Nawrocki A, Crossley K, Schache A. Hip flexibility and strength measures: Reliability and association with athletic groin pain. *Br J Sports Med.* 2009;43:739-744.
19. Delahunt E, Mcentee BL, Kennelly C, Green BS, Coughlan GF. Intrarater reliability of the adductor squeeze test in Gaelic games athletes. *J Athl Train.* 2011;46(3):241-245.
20. Gribble PA, Kelly SE, Refshauge KM, Hiller CE. Interrater reliability of the Star Excursion Balance Test. *J Athl Train.* 2013;48(5):621-626.
21. Munro AG, Herrington LC, Carolan M. Reliability of 2-dimensional video assessment of frontal-plane dynamic knee valgus during common athletic screening tasks. *J Sport Rehab.* 2012;21:7-11.
22. Jones R, Greig M. In-vivo measurements of tri-axial loading at the head during the rugby tackle. *Res Sports Med.* 2017;25(4):437-450.
23. Bahr R. Why screening tests to predict injury do not work – and probably never will…: A critical review. *Br J Sports Med*. 2016;50:776-780.
24. Malloy P, Morgan A, Meinerz C, Geiser C, Kipp K. The association of dorsiflexion flexibility on knee kinematics and kinetics during a drop vertical jump in healthy female athletes. *Knee Surg, Sports Traumatol, Arthrosc.* 2015;23(12):3550-3555.
25. Kuhman D, Paquette M, Peel S, Melcher D. Comparison of ankle kinematics and ground reaction forces between prospectively injured and uninjured collegiate cross country runners. *Hum Mov Sci*. 2016;47:9-15.

26. Hegedus E, McDonough S, Bleakley C, Cook C, Baxter G. Clinician-friendly lower extremity physical performance measures in athletes: A systematic review of measurement properties and correlation with injury part 1. The tests for knee function including the hop tests. *Br J Sports Med*. 2014;49(10):642-648.
27. Pairot de Fontenay B, Argaud S, Blache Y, Monteil K. Contralateral limb deficit seven months after ACL-reconstruction: An analysis of single-leg hop tests. *Knee*. 2015;22:309-312.
28. Delahunt E, Fitzpatrick H, Blake C. Pre-season adductor squeeze test and HAGOS function sport and recreation subscale scores predict groin injury in Gaelic football players. *Phys Ther Sport*. 2017;23:1-6.
29. Tak I, Glasgow P, Langout R, Weir A, Kerkhoffs G, Agricola R. Hip range of motion is lower in professional soccer players with hip and groin symptoms or previous injuries, independent of cam deformities. *Am J Sports Med*. 2016;44(3):682-688.
30. Bedi A, Warren R, Wojtys E, Oh Y, Ashton-Miller J, Oltean H, Kelly B. Restriction in hip internal rotation is associated with increased risk of ACL injury. *Knee Surg Sports Traumatol Arthrosc*. 2016;24:2024-2031.

Table 1. Summary of clinical screening test scores and loading response to the soccer-specific session.

Screening Test		Mean ± SD	Player Load		Mean ± SD
Anterior Reach (cm)	Dom	65.2 ± 5.7	3D Total (a.u)		283.4 ± 51.5
	Non-Dom	65.1 ± 5.2	Medio-Lateral (a.u)	Total	78.7 ± 33.8
Single Leg Hop (cm)	Dom	177.2 ± 17.0		-ve	39.2 ± 13.3
	Non-Dom	172.8 ± 18.2		+ve	39.5 ± 19.1
Knee to Wall (cm)	Dom	10.6 ± 3.1	Anterio-Posterior (a.u)	Total	120.0 ± 35.9
	Non-Dom	10.0 ± 3.2		-ve	13.3 ± 6.3
Hip Int. Rotation (°)	Dom	36.0 ± 7.3		+ve	106.7 ± 29.8
	Non-Dom	33.5 ± 7.0	Vertical (a.u)	Total	84.8 ± 21.4
Adductor Squeeze (mmHg)	0°	110.0 ± 16.4		-ve	3.6 ± 2.1
	45°	157.8 ± 18.4		+ve	81.3 ± 19.9
	90°	139.7 ± 19.1			

Table 2. Linear correlation coefficients r^2 between screening test and planar load.

	Anterior Reach		Single leg Hop		Knee to Wall		Hip Int. Rotation		Adductor Squeeze		
	Dom.	Non-D.	Dom.	Non-D.	Dom.	Non-D.	Dom	Non-D.	0º	45º	90º
Total 3D	0.10 (0.17)	0.10 (0.17)	0.05 (0.33)	0.10 (0.16)	**0.39 (<0.01)**	0.32 (0.01)	<0.01 (0.95)	0.04 (0.40)	0.04 (0.37)	0.01 (0.61)	0.01 (0.71)
X Total	< 0.01 (0.82)	< 0.01 (0.83)	0.04 (0.38)	0.11 (0.14)	0.10 (0.17)	0.06 (0.28)	0.04 (0.40)	0.24 (0.03)	0.03 (0.45)	<0.01 (0.94)	0.03 (0.42)
X-ve	0.12 (0.12)	0.10 (0.17)	0.12 (0.13)	0.12 (0.13)	0.28 (0.01)	0.30 (0.01)	0.03 (0.48)	<0.01 (0.81)	0.04 (0.37)	<0.01 (0.94)	<0.01 (0.62)
X+ve	< 0.01 (0.79)	< 0.01 (0.82)	0.01 (0.62)	0.08 (0.23)	0.03 (0.44)	< 0.01 (0.68)	0.09 (0.20)	0.31 (0.01)	0.02 (0.56)	<0.01 (0.90)	0.03 (0.44)
Y Total	0.09 (0.19)	0.10 (0.17)	0.02 (0.53)	0.03 (0.47)	**0.42 (<0.01)**	**0.36 (<0.01)**	0.01 (0.75)	<0.01 (0.97)	0.01 (0.73)	0.05 (0.36)	<0.01 (0.89)
Y–ve	0.07 (0.26)	0.07 (0.25)	0.01 (0.61)	0.02 (0.57)	**0.36 (<0.01)**	0.32 (0.01)	<0.01 (0.97)	<0.01 (0.87)	<0.01 (0.78)	0.06 (0.27)	<0.01 0.90
Y+ve	0.09 (0.18)	0.10 (0.16)	0.02 (0.53)	0.03 (0.46)	**0.43 (<0.01)**	**0.36 (<0.01)**	0.01 (0.72)	<0.01 (0.94)	0.01 (0.72)	0.04 (0.38)	<0.01 (0.86)
Z Total	0.24 (0.03)	0.23 (0.03)	0.05 (0.32)	0.10 (0.18)	**0.41 (0.02)**	**0.37 (<0.01)**	0.01 (0.62)	<0.01 (0.88)	0.09 (0.18)	0.01 (0.66)	<0.01 (0.92)
Z-ve	0.15 (0.09)	**0.41 (<0.01)**	0.04 (0.38)	0.04 (0.43)	0.25 (0.02)	0.08 (0.22)	<0.01 (0.97)	<0.01 (0.78)	0.06 (0.29)	0.01 (0.69)	0.02 (0.56)
Z+ve	0.24 (0.03)	0.20 (0.04)	0.06 (0.28)	0.11 (0.14)	**0.40 (<0.01)**	**0.37 (<0.01)**	0.01 (0.62)	<0.01 (0.88)	0.10 (0.17)	0.01 (0.69)	<0.01 (0.99)

Table 3. A stepwise hierarchical ordering of screening tests influencing planar loading.

	Step 1	Step 2	Step 3	Step 4
Total 3D	Dom knee-to-wall $r^2 = 0.39$ (<0.01)	Non-Dom Hop $r^2 = 0.56$ (0.02)		
X Total	Non-Dom Hip IntRot $r^2 = 0.24$ (0.03)	Non-Dom Hop $r^2 = 0.30$ (0.21)	Dom knee-to-wall $r^2 = 0.39$ (0.14)	
X-ve	Non-Dom knee-to-wall $r^2 = 0.30$ (0.01)	Dom Hop $r^2 = 0.51$ (0.01)		
X+ve	Non-Dom Hip IntRot $r^2 = 0.31$ (0.01)			
Y Total	Dom knee-to-wall $r^2 = 0.42$ (<0.01)	Dom Hop $r^2 = 0.52$ (0.07)		
Y–ve	Dom knee-to-wall $r^2 = 0.36$ (<0.01)	Dom Hop $r^2 = 0.43$ (0.14)	Adductor 45 Sq $r^2 = 0.48$ (0.22)	Dom Reach $r^2 = 0.53$ (0.20)
Y+ve	Dom knee-to-wall $r^2 = 0.43$ (<0.01)	Dom Hop $r^2 = 0.52$ (0.07)		
Z Total	Dom knee-to-wall $r^2 = 0.41$ (<0.01)	Non-Dom Hop $r^2 = 0.57$ (0.02)	Dom Hip IntRot $r^2 = 0.63$ (0.11)	
Z-ve	Dom Reach $r^2 = 0.41$ (<0.01)	Adductor 0 Sq $r^2 = 0.53$ (0.05)	Non-Dom Reach $r^2 = 0.61$ (0.09)	Non-Dom Hop $r^2 = 0.66$ (0.15)
Z+ve	Dom knee-to-wall $r^2 = 0.40$ (<0.01)	Non-Dom Hop $r^2 = 0.58$ (0.01)	Dom Hip IntRot $r^2 = 0.64$ (0.11)	

Figure 1. The screening battery comprising: (a) knee to wall, (b) hip internal rotation, (c) hip adductor squeeze test (shown at 45°), (d) single leg anterior reach, (e) single leg hop for distance.