TITLE: KINEMATICS DURING LOWER EXTREMITY FUNCTIONAL SCREENING TESTS – ARE THEY RELIABLE AND RELATED TO JOGGING?

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KINEMATICS DURING LOWER EXTREMITY FUNCTIONAL SCREENING TESTS – ARE THEY RELIABLE AND RELATED TO JOGGING?

ABSTRACT

Purpose: To investigate the within-day and between-day reliability of 3D lower extremity kinematics during five lower extremity functional screening tests and to assess the association between these kinematics and those recorded during jogging.

Methods: Peak three-dimensional lower extremity kinematics were quantified in 25 uninjured participants during five lower extremity functional tests and jogging. A nine camera motion analysis system (Qualysis Medical AB, Sweden) was used to capture three trials of all tests. All functional tests were repeated by 10 participants one to two days later. Visual 3D (C-Motion Inc, USA) and Labview were used to process all data. Intraclass correlation coefficients (ICC) and typical errors (TE) were used to assess within- and between-day reliability of all variables. Pearson correlation coefficients were used to evaluate the association between peak joint kinematics during the functional tests and jogging.

Results: For the majority of kinematic variables the within-day reliability was excellent (ICC ≥ 0.92) and the between-day reliability was excellent to good (ICC ≥ 0.80). The correlation between kinematics of the functional tests and jogging was generally large to very large (r = 0.59 to 0.93).

Conclusions: These results suggest these lower extremity functional screening tests should prove a useful clinical tool when assessing dynamic lower extremity alignment.

Key words: *Reliability, kinematics, lower extremity, functional tests*

BACKGROUND

Screening of individuals for risk of future injury and as a means to optimising performance has become common, particularly in professional sport but also at other competitive and recreational levels (Mottram & Comerford, 2008). When screening the lower extremity the use of functional tests to evaluate movement quality (neuromuscular control) is now highly recommended. Functional tests are frequently used to identify altered lower extremity kinematics during weight bearing activities in the belief this is linked to injury risk and peak performance. However it must be acknowledged the validity of these tests for predicting injury and/or performance remains unclear. Despite this traditional assessment of isolated joints and muscles alone is no longer considered adequate and the additional use of functional tests to assess multiple muscles, across multiple joints, in functionally orientated tasks is common (Mottram & Comerford, 2008). Physiotherapists utilise this information (primarily gained from visual observation) in their clinical decision making process when considering their prescription of exercises and also evaluating progress during rehabilitation.

The Small Knee Bend (SKB) (Mottram & Comerford, 2008; Reid, Stotter, Schneiders, Hing, & White, 2003; Sahrmann, 2002) and its variations (double leg, single leg, lunge, hop lunge) is a common lower extremity functional test used by physiotherapists and sports physicians to assess dynamic trunk and lower extremity alignment. This test (also known as a partial squat) is described by Sahrmann (2002) as part of a lower quarter examination. A single leg SKB has also been described as a specific screening test by Mottram (2008). Additionally it is common clinical practise, when indicated, to further evaluate dynamic trunk and lower extremity alignment by using a lunge (Crossley, Cook, Cowan, & McConnell, 2006) and hop lunge (Cook, 2006). Similar tests reported in the literature include single leg squats (SLS) (Zeller, McCrory, Kibler, & Uhl, 2003) and single leg step downs (Earl, Monteiro, & Snyder, 2007).

When using lower extremity functional tests, such as those described above, physiotherapists evaluate dynamic trunk and lower limb alignment. Poor dynamic alignment has been described as a combination of excessive trunk lateral flexion, pelvic drop, hip adduction and internal rotation, knee abduction, tibial internal or external rotation and foot hyperpronation (Earl, Hertel, & Denegar, 2005; Powers, 2003; Sahrmann, 2002; Willson & Davis, 2009). The resultant excessive medial displacement of the knee in the frontal plane has also been termed dynamic knee valgus (Bell, Padua, & Clark, 2008). The movements of concern to clinicians mostly occur in the frontal or transverse planes. Clinical observation of the position of the patella relative to a line extending vertically from the 1st or 2nd toes is also a common measure of frontal plane control (Bell et al., 2008; Hirth & Padua, 2007; Mottram & Comerford, 2008). Abnormal motion of the trunk, pelvis, hip and knee in these planes, observed during activities such as running, squatting and landing, is considered a key risk factor for the development of common injuries such as patellofemoral dysfunction (Powers, 2003).

Few studies have investigated the reliability of trunk, pelvic, hip, knee and ankle 3D joint kinematics during lower extremity functional tests. We are not aware of any studies reporting kinematic reliability during a SKB, lunge or hop lunge or any studies reporting the reliability of trunk and pelvic kinematics during any tests including the common SLS. Two studies have used 2D techniques to assess the reliability of frontal plane kinematics during a SLS (Levinger, Gilleard, & Coleman, 2007; Willson, Ireland, & Davis, 2006). Willson (2006) reported the measure was reliable within-day (ICC=0.88), while (Levinger et al., 2007) reported acceptable reliability within and between-days (ICC 0.88 and 0.74). Neither study reported an absolute measure of reliability. In addition to the lack of studies investigating the reliability of SLS, the generalisability of these to SKB is questionable. Although similar, and looking to assess the same alignment faults, there are subtle differences in the performance of SKB and SLS. The focus of a SLS is most often the flexion of the hip with associated trunk flexion. The SKB emphasises the flexion of the knee and ankle (while maintaining a relatively upright trunk position) in a pattern that possibly more closely simulates the stance phase of walking and running. Furthermore to standardise the performance of SLS, previous studies have relied on monitoring the amount of knee flexion (Claiborne et al., 2006; Levinger et al., 2007; Willson et al., 2006). This is not common clinically due to the extra time and equipment required. This combined with possible differences in the movement pattern make any reliability reported less generalisable to clinical tests such as SKB. The reliability of hip and knee joint 3D kinematics (but not trunk and pelvis) during a stepdown and lateral stepdown has also been reported to be acceptable (ICC= 0.70 to 0.88) (Bolgla, Malone, Umberger, & Uhl, 2008; Earl et al., 2005). Within-subject kinematic variation during functional tests is one important type of reliability for physiotherapists to consider if they want to visually assess and monitor performance of their clients (Hopkins, 2000). It is crucial to know if the kinematics are consistent enough from day to day for making clinical decisions. For example, a physiotherapist needs to know if following a rehabilitation programme the change in hip adduction noted visually during a lower extremity functional test is real or whether the change is due to expected kinematic variability with repeat testing. The reporting of absolute variability (such as typical error in degrees) also provides greater clinical meaning than the more commonly reported relative variability (such as ICC). Furthermore the reliability of these tests also needs to be established if they are to be used in longitudinal studies evaluating injury risk or the effect of rehabilitation interventions.

An advantage of functional testing is that it is thought to replicate the kinematics encountered during a task specific activity (Clark, 2001). The SKB test and its various extensions are considered useful in the clinic to gain an insight into the kinematics a client may exhibit during functional tasks such as walking, running, stair climbing and lunging. A recent study by Willson (2008) suggested a link between kinematics (2D frontal plane projection angle) during a single leg squat and more dynamic activities (running and jumping). These authors found that a group with patellofemoral pain had less internal hip rotation when squatting, jumping and running than a control group. Clinicians often assume these functional tests are an effective method of diagnosing actual functional movement dysfunction and consequently prescribing prevention or rehabilitation programmes. However the evidence for this is mostly anecdotal. Therefore the association between the kinematics recorded during SKB tests and those occurring during actual function (e.g. jogging) need investigation. This relates to the validity of the tests and when clinicians select a test they need to acknowledge issues relating to both reliability and validity (Clark, 2001).

To date, no research has reported the typical variation in trunk, pelvis, hip, knee and ankle 3D joint kinematics a participant would exhibit with various SKB tests within or between days. The use of SKB type tests as a clinical screening tool for walking and running gait also needs investigation.

PURPOSE

To investigate the within- and between-day reliability of peak 3D trunk and lower extremity kinematics during five lower extremity functional screening tests and to assess the association between these kinematics and those recorded during jogging.

Peak kinematics in the transverse and frontal plane during loading were chosen as they are frequently screened in the clinic and linked to risk of injury.

METHODS

Participants

Twenty five participants (mean age = 22±4 yr, mean height = 171±10 cm, mean weight = 66±12 kg) with no musculoskeletal problems volunteered for this study. The study was approved by the Auckland University of Technology Ethics Committee. All participants received verbal and written information about the study and gave written informed consent prior to testing.

Instrumentation

A University Motion Analysis Laboratory was used for all testing. This laboratory contains a nine camera motion analysis system (Qualysis Medical AB, Sweden) suitable for recording whole body 3D kinematics. Cameras, sampling at a rate of 240 Hz, were positioned to provide the optimum field-of-view of the area of the laboratory used for all testing. Prior to data collection the system was calibrated as per the manufacturer's protocol using a static calibration frame (to orientate the cameras with respect to the laboratory coordinate system) and a dynamic wand. During calibration with the dynamic wand average movement residue (RES) for the retro-reflective markers was less than 2 mm.

Prior to testing the trunk, pelvis and dominant leg of all participants were instrumented with 15 retro-reflective markers (19 mm diameter) secured to specific anatomical locations (bilateral acromion processes, bilateral ASIS's, sacrum, bilateral iliac crests, medial and lateral femoral epicondyles, mid-patella, medial and lateral malleoli, head of

5th metatarsal, head of 2nd metatarsal, posterior calcaneus). All markers were positioned by an experienced musculoskeletal physiotherapist based on palpation of appropriate anatomical landmarks (Figure 1).

Figure 1: Participant instrumented with markers (note medial knee and ankle anatomical markers used for skeletal model construction are not shown as they were removed during functional tests).

These anatomical markers provided a reference marker set for construction of a skeletal model using a commercial biomechanical analysis software programme (Visual 3D, C-Motion Inc, USA) To ensure optimal reproduction of marker placement during repeat testing, a marker pen was used to identify marker position and participants were asked to retain this until the repeat testing session conducted within two days of the initial test. The dominant leg was identified by asking each participant the leg they would use to kick a ball.

Two cluster marker sets (a group of four retro-reflective markers attached to a light weight rigid plastic shell) were also attached to the thigh and shank of the dominant leg (Figure 1). These marker sets were designed to track motion of the thigh and shank segments. It has been suggested that clusters are more accurate and practical for tracking motion than individual skin markers (Angeloni, Cappozzo, Catani, & Leardini, 1993) and four markers attached to a rigid shell is thought to be optimal (Cappozzo, Cappello, Della Croce, & Pensalfini, 1997; Manal, McClay, Stanhope, Richards, & Galinat, 2000). All anatomical markers and the cluster marker sets were attached directly to the skin with double sided adhesive tape. The cluster marker sets were additionally secured with elasticized Velcro straps of various lengths designed specifically for this purpose.

Testing protocol

All twenty five participants attended the Motion Analysis Laboratory on one occasion. Ten participants (40%) returned on a second occasion for repeat testing one to two days later. Following instrumentation of the retro-reflective markers a static trial was first collected in which participants were asked to stand still with foot placement standardized to the laboratory coordinate system.

Performance of the five functional tests was then randomized among participants. All participants were given standardized verbal instructions prior to each test (Table 1) and the researcher demonstrated each test. Participants were required to keep their heels on the ground throughout each test (except the step-down) in order to try and standardize the range of hip and knee flexion without the need for additional monitoring and equipment. These simple instructions increase the clinical utility of the tests. Practice for all tests was allowed until the researcher was confident the test was performed consistently (this usually required 3-5 practice attempts). All tests were performed within the same area of the laboratory and the speed of each test was set by a three second count made by the researcher (verbally counted as “one and two and three”) during the dorsiflexion/knee flexion phase of each test. Prior to the SKB and single leg SKB tests subjects walked three steps to move into the test area of the laboratory and take up their natural stance position prior to commencing each test.

During all tests participants were instructed to maintain visual focus on a cross positioned on a wall directly in front of them at eye level. Pilot testing showed this to be a useful method for maintaining an upright trunk position, improving consistency and it was also thought to most appropriately simulate a functional head and trunk position. Participants performed three repetitions of each test and were also recorded jogging the length (~10 m) of the laboratory. Jogging trials were repeated until the researcher was convinced that three consistent trials had been collected (this usually required approximately five attempts). Mean jogging velocity, estimated from the anterior velocity of the sacral marker in the laboratory coordinate system, was 2.9 ±0.4 m/s.

Table 1: Description of the five functional tests used in the study.

Functional test	**Test description**
Small knee bend (SKB)	Starting from a standing position participants performed a partial squat (hip and knee flexion) with the trunk maintained in an upright position. Participants were instructed to continue the SKB until they reached maximum dorsiflexion without lifting their heels and then return to upright standing.
Single leg small knee bend (dominant leg)	Standing on the dominant leg only, with the contralateral hip in neutral and knee flexed to approximately 80 degrees, participants performed a SKB as described above.
Lunge (dominant leg)	From a standing position participants were instructed to lunge forward (leading with their dominant leg) a distance of approximately one and a half times the length of their normal gait stride. As they moved into single leg stance (on the dominant leg, with the contralateral leg off the ground) they flexed the hip and knee while maintaining an upright trunk. Participants were instructed to continue the lunge until reaching maximum dorsiflexion of the stance leg without lifting their heel.
Hop lunge (dominant leg)	From a standing position participants were instructed to jump forward a distance of approximately 1.0 m and on landing on the dominant leg to flex the hip and knee. Participants were instructed to continue the lunge until reaching maximum dorsiflexion of the dominant leg without lifting their heel.
Step-down	Leading with the non-dominant leg, participants stepped slowly down from a step 20 cm high.

Data processing

All static and motion (functional test and jogging) trails were tracked using the Qualysis motion capture software and exported to Visual 3D (C-Motion Inc, USA). In Visual 3D the static trial, combined with the height and weight data of each participant was used to create geometric objects of appropriate shape and mass to represent each body segment (trunk, pelvis, thigh, shank and foot). All lower limb segments were modeled as frusta of right cones and the pelvis and trunk segments were modeled as right elliptical cylinders. Together these segments formed a 6-degree-of-freedom, rigid link biomechanical model. Visual 3D defines joints in the model as places where the distal end of one segment meets the proximal end of another segment and analysis of joint motion is based solely on the relative motion between the segments.

In Visual 3D the rigid link model created from the static file was then assigned to all the imported motion files to allow calculation of relevant kinematic data. The data from the motion files was filtered with a second-order Butterworth bidirectional low-pass filter with a cut-off frequency of 6 Hz. The Cardan sequence y-x-z was used for the calculation of joint angles which was equivalent to flexion/extension, abduction/adduction, axial rotation and in this case equivalent to the Joint Coordinate System described by Grood (1983). The only exception to this was for calculation of pelvic angle with respect to the laboratory where we used the sequence z-x-y (axial rotation, obliquity, tilt) which is recommended in the Visual 3D documentation based on the suggestions of Baker (2001). Joint angles were not normalised to the static standing trial.

All kinematc data for the trunk, pelvis and lower limb were exported as 'text' files for importing into Labview for further analysis. The Labview VI processed the trunk, pelvis and lower limb, kinematic data and output the peak joint angles during the knee flexion phase of each functional test and the stance phase (start to maximum knee flexion only) of jogging. The mean of each of these variables, across the three repetitions of each functional test and jogging was then used in the between-day statistical analyses. We also output the maximum medial position of the patella marker in the frontal plane (y coordinate in the laboratory coordinate system) We have termed this medial knee displacement (MKD) and analysed it in the same manner as for the joint angles described above.

Statistical analyses

Proc mixed in Statistical Analysis Systems (SAS), “Version 9.1, SAS Institute, Cary, NC” was used to estimate within subject trial to trial variability within a day and between days. The trial to trial variability within a day was the residual error in the model. The model allowed estimation of a different residual for day 1 and day 2. The model included the random effect of Subject by Day. The model also included fixed effects (interaction of Day and Trial) to allow for a change in the mean between all trials on both days. The mixed model allowed calculation of within- and between-day reliability expressed as a typical error (TE) in degrees and Intra-class correlation coefficient (ICC) with 90% confidence limits. The ICC we calculated in SAS is equivalent to an ICC (2,1). Typical error is interpreted as the expected variation in peak joint angle when one individual is tested on repeat occasions. Additionally processing of errors in SAS was completed to estimate the ICC and typical error for different numbers of trials. The ICC classifications of Fleiss (1999) were used to describe the magnitude of ICC values (less than 0.4 was poor, 0.4 to 0.75 was fair to good, and greater than 0.75 was excellent).

Using the data from initial testing only (all twenty five participants), Pearson correlation coefficients were calculated to assess the magnitude of the association between peak joint angles during the functional tests and those during jogging. The magnitudes of these correlations were described as trivial (0.0-0.1), small (0.1-0.3), moderate (0.3-0.5), large (0.5-0.7), very large (0.7-0.9), or extremely large (0.9-1.0) (Hopkins, Marshall, Batterham, & Hanin, 2009). Using this same data mean peak joint angles and standard deviations have been calculated for each of the functional tests.

RESULTS

The mean joint angles recorded during the knee flexion phase of each functional test are described in Table 2. Angles appear similar across all tests with a few notable exceptions. The step-down test recorded a much higher knee flexion angle (91 degrees) than the other tests and SKB recorded a relatively low peak hip adduction angle (2 degrees). On visual inspection of the data most peak angles in the frontal and transverse planes generally occurred between mid-range and maximum knee flexion.

Table 2: Peak angle (º) during the knee flexion phase of each functional test for three trials (all 25 participants, mean ±SD).

		Hop Lunge	**Single Leg SKB**	**SKB**	**Step-down**	**Lunge**
Ankle	Dorsiflexion	17 ±5	19 ±7	17 ±7	17 ±7	19 ±7
	Eversion	16 ±5	10 ±4	13 ±3	16 ±5	13 ±5
Knee	Flexion	68 ±9	65 ±13	68 ±15	91 ±7	68 ±12
	Abduction to adduction*	3 ±4 to 9 ±5	0 ±3 to 9 ±5	0 ±3 to 7 ±5	0 ±3 to 11 ±5	1 ±4 to 8 ±5
Hip	Flexion	46 ±12	34 ±18	40 ±18	31 ±10	41 ±14
	Abduction to adduction*	-3 ±3 to 9 ±5	4 ±3 to 11 ±5	-2 ±4 to 2 ±3	1 ±4 to 10 ±4	3 ±4 to 13 ±6
	External to internal rotation†	-3 ±6 to 4 ±5	0 ±6 to 5 ±7	0 ±6 to 4 ±6	-1 ±5 to 5 ±6	0 ±6 to 6 ±7
Pelvis	Lateral tilt (L to R)	-4 ±4 to 1 ±3	-2 ±4 to 3 ±3	-2 ±2 to 0 ±2	-6 ±3 to 3 ±3	-4 ±4 to 1 ±3
	Transverse plane rotation (R to L)	0 ±4 to 9 ±4	-1 ±4 to 3 ±3	-1 ±2 to 2 ±3	-5 ± 4 to 1 ±4	1 ±4 to 7 ±5
Trunk	Lateral tilt (L to R)	-1 ±3 to 4 ±3	1 ±2 to 4 ±2	-1 ±1 to 0 ±1	-1 ± 2 to 3 ± 2	-1 ±2 to 2 ±2
	Transverse plane rotation (R to L)	-2 ±4 to 3 ±4	-1 ±4 to 2 ±4	-1 ±3 to 1 ±3	-4 ± 4 to 2 ±4	0 ±4 to 3 ±3

*range is minimum to maximum where +ve = adduction.

†range is minimum to maximum where +ve = internal rotation.

Based on the use of three trials, the within-day ICC values for all measured variables (ICC = 0.79 to 1.0; Table 3) are generally higher than the between-day ICC values (ICC = 0.46 to 0.99; Table 4). Within-day ICC's were all greater than 0.90, except for trunk lateral flexion during Hop Lunge and Lunge (ICC = 0.79). Within-day typical errors for all variables, representing the typical variation for an individual participant on repeat tests, ranged from 0.5 to 1.3 degrees. The within-day ICC and typical error range across all tests was small indicating consistent reliability irrespective of the test.

Table 3: Within-day reliability of the peak angle (º) and medial knee displacement (cm) for all five functional tests

		Mean Typical Error (range)		ICC range	
Number of trials		**3**	**10**	**3**	**10**
Trunk	Lateral flexion	0.9 (0.3-1.6)	0.5 (0.2-0.9)	0.79-0.93	0.92-0.98
	Rotation	0.8 (0.5-1.1)	0.4 (0.3-0.6)	0.92-0.97	0.98-0.99
Pelvis	Lateral tilt	0.8 (0.6-1.0)	0.4 (0.3-0.5)	0.94-0.98	0.98-0.99
	Rotation	0.8 (0.6-1.0)	0.4 (0.3-0.5)	1.0-1.0	1.0-1.0
Hip	Flexion	1.3 (0.97-1.8)	0.7 (0.5-1.0)	0.99-1.0	1.0-1.0
	Adduction	0.8 (0.4-1.1)	0.5 (0.2-0.6)	0.97-0.99	0.99-1.0
	Internal rotation	0.7 (0.4-0.8)	0.4 (0.2-0.5)	0.99-1.0	1.0-1.0
Knee	Flexion	1.3 (1.1-1.7)	0.7 (0.6-0.9)	0.94-0.99	0.98-1.0
	Abduction	0.5 (0.4-0.9)	0.3 (0.2-0.5)	0.93-0.99	0.98-1.0
Ankle	Dorsiflexion	0.7 (0.5-1.0)	0.4 (0.3-0.5)	0.97-1.0	0.99-1.0
	Eversion	1.0 (0.7-1.4)	0.5 (0.4-0.8)	0.94-0.99	0.98-1.0
Knee	MKD	0.5 (0.2-0.7)	0.3 (0.0-0.4)	0.94-0.98	0.98-1.0

Typical Error 90% CL ~×⁄÷1.20, lowest ICC 90% CL ~ ±0.14

The majority of the between-day ICC's were greater than 0.8 and the typical errors ranged from 1.2 to 3.9 degrees. The poorest between-day reliability was for trunk lateral flexion during the Single Leg SKB (ICC = 0.46), however the typical error was still only 1.2 degrees. The trunk generally showed the worst between-day reliability. The hip showed the most consistent between-day reliability in all planes (ICC's = 0.87 to 0.98).

The additional processing of the errors did not suggest substantial improvements in within or between-day reliability if the number of trials was increased to ten (Table 3 and 4).

Table 4: Between-day reliability of the peak joint angle (º) and medial knee displacement (cm) for all five functional tests

		Mean Typical Error (range)		**ICC range**	
Number of trials		**3**	**10**	**3**	**10**
Trunk	Lateral flexion	1.2 (0.4-1.7)	0.9 (0.4-1.6)	0.46-0.84	0.51-0.92
	Rotation	2.0 (1.8-2.6)	1.5 (1.1-2.2)	0.61-0.86	0.62-0.89
Pelvis	Lateral tilt	1.4 (0.9-2.1)	1.4 (0.8-2.0)	0.70-0.89	0.72-0.92
	Rotation	1.6 (1.1-1.9)	1.4 (1.0-1.8)	0.90-0.99	0.90-0.99
Hip	Flexion	3.9 (2.8-5.4)	3.7 (2.7-5.2)	0.90-0.98	0.91-0.98
	Adduction	1.9 (1.0-2.4)	1.8 (1.0-2.3)	0.87-0.97	0.88-0.98
	Internal rotation	3.1 (2.8-3.3)	3.0 (2.8-3.3)	0.91-0.97	0.91-0.97
Knee	Flexion	2.8 (2.4-3.7)	2.7 (2.2-3.6)	0.86-0.97	0.89-0.97
	Abduction	1.9 (1.7-2.3)	1.8 (1.7-2.3)	0.67-0.76	0.68-0.77
Ankle	Dorsiflexion	2.3 (2.0-2.4)	2.2 (1.9-2.4)	0.87-0.90	0.88-0.91
	Eversion	2.4 (1.4-2.7)	2.2 (1.2-2.6)	0.62-0.94	0.64-0.96
Knee	Medial knee displacement	1.0 (0.0-2.0)	1.0 (0.0-2.0)	0.59-0.93	0.60-0.95

Typical Error 90% CL~×/÷1.47, lowest ICC 90% CL~±0.47, highest ICC 90% CL~±0.02

The Pearson correlation coefficients suggested moderate to very large correlations between many of the peak ankle, knee and hip angles recorded during the functional tests and those recorded during jogging (r = 0.53 to 0.93; Table 5). The strongest correlations (r ≥ 0.75) for two or more functional tests existed for ankle inversion, knee adduction, hip adduction and hip internal and external rotation. The confidence limits for the majority of ankle, knee and hip correlations indicated the true correlations were very likely to be at least moderate (≥ 0.3) and likely to be large (≥ 0.5). The correlation for peak pelvic tilt was also high (r = 0.60 to 0.72), while trunk angles generally showed the poorest correlations (r = -0.15 to 0.53).

Table 5: Correlations between peak joint angles during the functional tests and jogging expressed as Pearson correlation coefficients

		SKB	Single Leg SKB	Lunge	Hop Lunge	Stepdown
Ankle	Eversion	0.77	0.76	0.60	0.79	0.60
	Inversion	0.74	0.83	0.72	0.65	0.78
Knee	Abduction	0.70	0.70	0.79	0.66	0.76
	Adduction	0.84	0.75	0.69	0.61	0.78
Hip	Adduction	0.80	0.73	0.75	0.71	0.65
	Abduction	0.82	0.70	0.70	0.72	0.53
	Internal rotation	0.90	0.89	0.87	0.85	0.84
	External rotation	0.86	0.89	0.91	0.90	0.93
Pelvis	Lateral tilt	0.71	0.60	0.65	0.64	0.72
	Rotation	0.59	0.62	0.68	0.23	0.66
Trunk	Lateral flexion	0.09	0.10	0.18	-0.15	0.27
	Rotation	0.28	0.40	0.19	0.23	0.53

Pearson correlation coefficient 0.1 90% CL~±0.33, 0.6 90% CL~±0.22, 0.9 90% CL~±0.7

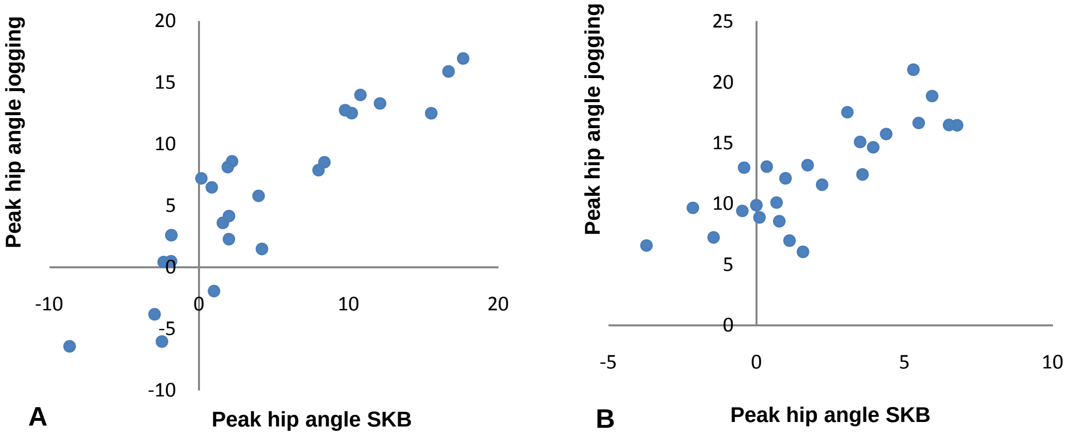

*Figure 2: Example scatter plots showing the association between SKB and jogging. Plot **A** shows peak transverse plane angles (-ve = external rotation), plot **B** shows peak frontal plane angles (-ve = abduction).*

DISCUSSION

The first purpose of this study was to investigate the within-day and between-day reliability of 3D joint kinematics during five lower extremity functional screening tests commonly used by physiotherapists in clinical practise. The findings indicated the within-day reliability of all kinematics was excellent and the between-day reliability of the majority of kinematics was good to excellent. To our knowledge this is the first study to report the 3D kinematic reliability of the trunk, pelvis, hip, knee and ankle during these specific functional tests. Previous studies have reported the reliability of some of these kinematics in similar but not identical tests such as stair descent (Bolgla et al., 2008), drop jump (Ford, Myer, & Hewett, 2007) and SLS (Zeller et al., 2003). While these are obviously also useful assessment tests the instructions, test protocols and kinematics involved are subtly different to most of the SKB movement tests investigated in the current study (step-down test excepted).

Within-day reliability was better than between-day for all tests which supports the findings of previous studies investigating the reliability of 3D joint kinematics during gait and other lower extremity functional tests (Ford et al., 2007; Kadaba et al., 1989). Ford (2007) reported on the reliability of peak lower extremity 3D kinematics when landing from a drop vertical jump in a group of 11 school soccer players. They concluded the reliability of the majority of kinematics was excellent to good (within-day ICC = 0.90, 95%CI 0.86-0.95, between-day ICC = 0.77, 95%CI 0.72-0.82). This is similar to the reliability reported for kinematics during normal adult gait (Kadaba et al., 1989) and similar to the reliability seen in the current study. The typical errors reported by Ford (2007) are also in accordance with those reported in the current study (within-day 0.9° to 3.2°, between-day 1.3° to 5.5°). Other studies have reported comparable reliability during other lower extremity functional tests. Earl (2007) reported reliable between-day peak 3D joint kinematics (ICC ≥ 0.84) during a drop vertical jump and single-leg step-down, in a group of males and females in their early 20's, for variables including rearfoot eversion, knee flexion/abduction/internal rotation and hip adduction/internal rotation. Kernozek (2005) reported good between-day reliability (ICC = 0.79 to 0.93) for a drop landing in a group of male and female recreational athletes (variables assessed were peak ankle plantarflexion/pronation, knee flexion/valgus and hip flexion/adduction). Bolgla (2008) reported similar reliability for mean hip joint kinematics (internal rotation and adduction) during the stance phase of a stair descent task (ICC = 0.75 to 0.88) in a group of females in their early 20's.

Of importance to clinical use is the excellent between-day reliability of peak hip kinematics in all planes in the current study. The role of hip motion in the frontal and transverse planes has been a focus of many recent studies investigating lower extremity alignment and risk of injury (Cowan, Crossley, & Bennell, 2008; Reiman, Bolgla, & Lorenz, 2009). Also of clinical relevance is our reporting of trunk and pelvis reliability which does not appear common in previous studies. The within-day reliability was similar to other segments as was the between-day reliability of the pelvis. However the between-day reliability of the trunk was somewhat less reliable. Additionally, except for the step-down test, knee flexion in the current study ranged from 65° to 68° This is in contrast to maximum angles of up to 96° (Earl et al., 2007), 95° (Zeller et al., 2003), and 89° (Kernozek et al., 2005) reported in previous studies using different lower extremity functional tests. The lesser knee flexion in the current study may make the SKB tests more appropriate for clinical screening of trunk and lower extremity alignment during walking and jogging gait (we noted that the average maximum knee flexion during the stance phase of jogging in our participants was 45 ±6°). Previous authors investigating single leg squat have used additional monitoring to limit knee flexion to 45° (Levinger et al., 2007) and 60° (Claiborne et al., 2006), similar to the angles we recorded. Additionally (J. D. Willson & I. S. Davis, 2008) determined hip and knee kinematics of interest to be those at 45° knee flexion during a single leg squat. Maximum hip and knee flexion showed excellent reliability (ICC = 0.86 to 0.98) demonstrating the ability of participants to produce a consistent range of sagittal plane motion. This was achieved with very simple instructions to the participants and without the need for complicated and time consuming monitoring. Zeller (2003) highlighted the need for controlling the depth of a single leg squat when assessing lower extremity kinematics and this has been noted as a limitation in other studies (Dwyer, Boudreau, Mattacola, Uhl, & Lattermann, 2010). In terms of test validity this is important as the maximum frontal and transverse plane deviations need to be assessed across the same range of sagittal plane motion on any given occasion for tests to be comparable. Increases in frontal plane motion, with increases in sagittal plane motion, have been reported in previous studies of kinematics during lower extremity functional tests (Kernozek et al., 2005; Russell, Palmieri, Zinder, & Ingersoll, 2006; Zeller et al., 2003).

As well as joint angles we also investigated the reliability of MKD (based on patella position) as this is commonly used by physiotherapists as a means of assessing dynamic lower extremity alignment. The excellent within-day reliability (ICC = 0.94 to 0.98) was again better than between-day (ICC = 0.62 to 0.94). However the between-day reliability was likely to be higher than reported as we failed to adequately standardise the medial position of the patella at the start of each test, between days. Thus we suggest that maximum MKD is likely to show acceptable reliability both within- and between-days. What remains unclear is whether or not the position of the patella is a good indicator of lower extremity 3D joint kinematics and this is a question that requires further research. It has been suggested that patella position in the frontal plane is a clinical indicator of femoral adduction and internal rotation (Bell et al., 2008), but there appears to be little evidence to support this claim. Willson (2008) recently described the 2-D frontal plane projection angle (FPPA) which uses an anterior knee marker at the mid-point of the femoral condyles (marker placed on the patella) to assess dynamic lower extremity alignment. They concluded that this angle was moderately associated with 3-D hip adduction and knee external rotation during single-leg squats, running and jumping.

There does not appear to be any consistent difference in the reliability between the various SKB tests and in fact the narrow range of typical errors suggests similar reliability. Intuitively we anticipated that the SKB (double leg stance throughout) may have been more reliable as it was the simplest test to perform and provided the least challenge to stability. This was however not the case and the within- and between-day typical errors reported for all kinematics, across all tests, were generally small (mostly between 1 and 4 degrees). This gives an indication to physiotherapists as to the absolute variation they can expect for any given client between consecutive tests. However it must be recognised that in visual observation clinicians cannot decompose joint motion into its 3D components. Thus any variation observed visually will be a composite (addition) of the typical errors reported in the individual planes, further confounding visual assessment. Even so interpretation of the ICC's alongside these typical errors provides evidence for physiotherapists that what they are observing on any given occasion is repeatable and thus representative of a client's kinematics. As has been noted by previous authors this is better than interpretation of the ICC's alone due its sensitivity to the heterogeneity of values between participants (Hopkins, 2000). One caution here is that we repeated the tests over a one to two day time period and this may not represent the typical error over longer timeframes.

Multiple factors are suggested to contribute to variability in repeat 3D motion analysis testing including errors due to marker placement. In contrast to previous studies we attempted to eliminate marker placement as a source of variation by marking the skin. This has been suggested by others as a way to improve the accuracy of marker reapplication (Ford et al., 2007). We also used standardised marker placement by a single investigator. The variability observed between tests is thus likely to mostly represent the altered movement performance of the individual participants. This was the major source of variation of interest in the current study as it is the most clinically relevant when considering the use of these functional tests. When considering clinical use of the tests it was encouraging to see the reliability of kinematics in the frontal and transverse planes as these are the movements most commonly linked to risk of lower extremity injury. We did investigate the influence of an increased number of trials on the reliability of the functional tests. This additional processing of errors suggested that the use of three trials (as is likely to occur in common clinical practice) provides similar reliability to the use of ten trials. The performance of extra trials does not appear warranted given the time that would be involved and the very small reductions in typical errors predicted.

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A secondary purpose of this study was to investigate the association between the peak 3D joint kinematics during the functional tests and those occurring during jogging. The results show that for many of the variables of interest there is a moderate to strong association suggesting that participants with higher peak angles in the functional tests also had higher peak angles in jogging. A caution here is that this should not be interpreted as the absolute angles agreeing as can be seen from the scatter plots in

Figure 2. This association does however provide some preliminary support for the use of these tests as a screening tool and specifically for screening peak lower extremity kinematics during the loading period of the stance phase in jogging gait. There are obvious clinical advantages involving space and equipment which make the use of SKB tests more feasible than direct assessment of jogging gait. As the speed of the movement during SKB is also slower than with jogging it is likely that physiotherapists will be able to visually rate movement with greater reliability and validity. This association between SKB and jogging appears strongest for hip kinematics. As noted earlier there has been increasing interest recently in the the role of the hip in knee dysfunction (Reiman et al., 2009) We further caution here however that we are not suggesting the SKB tests can take the place of jogging gait assessment. We have not performed a comparison of kinematics throughout (or at specific time points during) the SKB tests and jogging gait cycle which would be required before this could be contemplated.

A further limitation of this study is the uninjured population that we investigated. The reliability of these lower extremity functional tests in a population with lower extremity injury, such as patellofemoral syndrome, needs further investigation. However the current results provide useful information for the use of the tests when attempting to predict future injury in a screening situation. A further limitation is the small sample size used to assess the reliability of the functional tests. This obviously leads to greater uncertainty in the true magnitude of the reliability in the population. Precision for a correlation is thought to be adequate when the uncertainty in the estimate (represented by its confidence interval) does not span more than two qualitative magnitude thresholds (Hopkins & Manly, 1989). Thus we appear to have adequate precision for within-day ICC's and Pearson correlations greater than 0.8 and for between-day ICC's of greater than 0.9. The lower correlations still provide useful information but they must be interpreted with more caution. A further limitation of the study is our lack of control over jogging velocity and thus we cannot state that participants were running at a constant velocity. It should also be noted that peak 3D transverse and frontal plane hip and knee angles may occur in the second half of stance phase of jogging and our analysis only included the first half.

CONCLUSION

In healthy participants the reliability of peak 3D kinematics during the descent phase of these lower extremity functional tests is acceptable for the majority of kinematic variables of interest to physiotherapists. There is a moderate to strong association between these peak kinematics and those recorded during jogging. Based on these results SKB lower extremity functional movement tests should be useful in helping physiotherapists make clinical decisions regarding trunk and lower extremity dynamic alignment and risk of injury.

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