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ASSESSING MOVEMENT QUALITY USING THE HIP AND LOWER LIMB MOVEMENT SCREEN: DEVELOPMENT, RELIABILITY AND POTENTIAL APPLICATIONS

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Running Title: The Hip and Lower Limb Movement Screen

ABSTRACT

Background: An active lifestyle has many health benefits but intensive exercise and low grade repetitive trauma may impact the health of joints. Good quality, controlled movement, may reduce abnormal loading on joints and help prevent injury or when injuries do occur, prevent post-traumatic osteoarthritis. Screening tools to visually assess movement quality can be used to prescribe appropriate exercise interventions to improve movement quality. An assessment tool that focuses on hip movement control is needed for use in clinical and field environments.

Purpose: To describe a new screening tool that assesses control of the hip, pelvis and lower limbs, the Hip and Lower Limb Movement Screen (HLLMS), and test its intra- and inter-rater reliability.

Methods: The HLLMS includes five tests: small knee bend (SKB), standing hip flexion to 110°, side-lying hip abduction with the leg laterally rotated, SKB with trunk rotation and deep squat. Reliability was tested in two samples of young footballers aged 16-19 years; intra-rater in n=20 and inter-rater reliability in n=14. Percentage agreement (PA) and First Order Coefficient (AC1) were calculated.

Results: Intra-rater reliability was excellent with almost perfect agreement for the overall HLLMS (PA 96%; AC1 0.93), with strong inter-rater reliability (PA 88%; AC1 0.82).

Conclusions: The HLLMS can identify movement quality reliably in young community footballers. Poor movement patterns identified using the HLLMS are intended to inform the design of targeted exercise programmes to improve movement quality and reduce injuries or prevent the progression of injuries to post-traumatic OA.

KEYWORDS: Young Footballers, Movement Patterns, Movement Screening Tool

1. INTRODUCTION

Joint damage, whether due to a single traumatic injury or to repetitive abnormal loading, can contribute to osteoarthritis (OA), which is a substantial cause of disability. Knee injury is the classic example of a traumatic event increasing the risk of OA. Prospective studies report a 10-fold increased risk of developing knee OA 12-20 years post-injury compared with an uninjured population [87]. At the hip, cam morphology of the femur, which is an asphericity of the femoral head, also has an increased risk of later hip OA [2]. For cam morphology, however, it is not a single traumatic event that contributes to the increased risk. Instead, altered joint loading [7, 75, 92] is thought to be the primary driver of hip OA in this young population.

For both post-traumatic OA [109] and OA due to altered loading [10], young sporting people are at increased risk. Post-traumatic OA is recognised as an increasing burden in young adults [4, 109]. Cam morphology itself is thought to result from vigorous sports activity during the critical stages of skeletal development [3, 81]. However, not all individuals with cam morphology develop femoroacetabular impingement syndrome (FAIS), which is the triad of symptoms, morphology, and clinical signs [44]. Altered movement at the hip is likely a contributing factor not only to the morphology but also to the onset of symptoms.

Reducing in the risk of future OA is important both because of the economic burden of the disease and the negative impact on quality of life [18]. Strategies to prevent OA or delay its progression through identifying modifiable factors, such as abnormal movement patterns [10, 12] may help reduce the impact of OA. Movement screening tools have gained popularity in the clinical setting to predict injury risk and/or guide injury prevention programmes [21]. Kiesel et al [53] suggested that range of motion (ROM) and strength measurements are not able to measure fundamental changes in motor control following injury. Movement screening tests are comprehensive and challenge components of ROM, muscle strength and flexibility but also coordination, proprioception and motor control of multiple body regions, which can be assessed at the same time by observing movement quality, defined as optimal motor control and joint alignment [28, 29, 57, 90, 91, 95]. Therefore, whole body tasks to assess changes in motor control are considered better than traditional measurements such as ROM and strength [53]. Tests to evaluate movement control, termed "movement screening", have been recommended to assess movement quality to identify altered kinematics in the belief that this is linked to injury risk and peak performance [107], and are considered important to identify dysfunction or abnormal movement patterns [41].

Identifying, addressing and defining movement is complex due to limited understanding of the most efficient movement [78]. However, movement screening tools to assess movement quality involve qualitative identification and rating of movement compensations, asymmetries, impairments and inefficiency of movement control [110] and can be evaluated with tests in which a person is asked to cognitively control movement at a specific joint (e.g. hip) while moving an adjacent joint [17, 26, 35]. Identified movement compensations, asymmetries, impairments and inefficiency of movement control may lead to a disturbance or abnormality in the movement system. In turn this may cause a loss of movement precision, contributing to repeated stresses to tissue, alterations in control strategies and mechanical overload [28, 77, 91], possibly leading to pain [48, 51].

The Functional Movement Screen (FMS) is the most widely used movement screening tool in sporting and occupational environments, and has been shown to be valid [14] and reliable [14, 31]. The primary use of the FMS is for injury prediction but evidence of its predictive ability is conflicting in systematic reviews and meta-analyses indicating the FMS is not predictive [39, 69, 110] and is predictive [14]. These findings suggest the utility of the FMS may be limited to specific situations and led Bittencourt et al [13] to propose that the role of movement screening change from injury risk prediction to injury pattern recognition.

Existing movement screens lack specific focus on assessing control of the hip, pelvis and lower limb joints. Samar et al [93] proposed that the FMS is not appropriate for assessing hip dysfunction, as it does not correlate with the Timed 6-m Hop and Triple Hop Distance tests, which are tools to assess hip dysfunction. Also, the FMS has no unilateral weight-bearing test, which is a common task needed in daily functions or sports [9] and more likely to highlight movement compensations than bilateral tasks[62]. To address this problem of lack of focus on hip control, the Hip and Lower Limb Movement Screen (HLLMS) was developed to assess movement quality. The purpose of this screen is to inform exercise programmes to maintain lower limb joint health by ensuring good alignment and preventing abnormal loading on joints. Such interventions aim to prevent damage that could lead to OA or for secondary prevention of OA post-trauma [4]. The present paper describes the battery of movement tests comprising the HLLMS, examination of its intra- and inter-rater reliability using the model of young male footballers, and potential applications in various cohorts, sports and occupations.

2. METHODS

This methodology consists of two parts: firstly, a full description of the newly developed HLLMS, followed by intra- and inter-rater reliability testing of the screen. The study was conducted in accordance with the guidelines of the Declaration of Helsinki and was approved by the Faculty of Health Sciences Ethics Committee at the University of Southampton. Written informed consent was obtained from each participant.

2.1 Development and Description of the HLLMS Tool

The incidence of FAIS provides a useful model for developing OA prevention programmes, as retired professional players have higher incidence of hip OA and total hip replacement surgery than the general population [98, 102]. The HLLMS was first developed for young professional footballers to characterise their movement faults [15, 17]. Current literature and input from collaborating experts were used to develop optimal benchmark criteria for the HLLMS. The benchmark criteria were developed to challenge the hip and lower limb to exaggerate the movement compensations for an active population, possibly indicating hip and/or lower limb dysfunction [32, 56, 60, 73, 105]. For example, movement disorders exist in people with FAIS, showing smaller squat depth [56] and reduced posterior pelvic tilt [8, 58], ipsilateral trunk lean and pelvic rise towards the symptomatic hip [33], greater hip flexion and anterior pelvic tilt [61] and greater peak trunk flexion angles [47]. Also, patellofemoral pain (PFP) has been associated with an increased peak hip adduction, internal rotation, contralateral pelvic drop and dynamic valgus index [72, 96, 105]. These movement abnormalities relate to the criteria used in the HLLMS of anterior pelvic tilt, trunk leaning forward, femoral adduction/medial rotation (dynamic valgus), hip hitching/drop and posterior pelvic tilt. Preliminary findings from professional young footballers showed restricted internal hip rotation and poor movement control of hip flexion and medial rotation [15, 17], in one or more criteria compared to the benchmark, indicating movement faults in the HLLMS were: increased hip flexion, trunk leaning forwards, hips swaying back, femoral line moving medially, hip hitching and hip or pelvis rotation following the trunk [15, 17]. The HLLMS was then applied to recreational footballers and refined after preliminary feasibility and reliability testing, to produce the current screen, for which preliminary intra- and inter-rater reliability testing is described in the present paper. The screen is currently being tested in other cohorts, as outlined later in the discussion.

Although the movement screening tool focuses on hip and pelvic control, it also evaluates distal lower limb movements and is thus termed the HLLMS. The screen comprises five tests that can be performed in the clinic or field environment that do not require equipment. During the test manoeuvres, the rater observes the quality of the movement against benchmark criteria, by assessing the presence or absence of a deviation using a yes/no dichotomous scale, taking approximately 15 minutes to complete all the tests. The origins of each test and their purpose in the context of the HLLMS are given below. The test description and benchmark assessment criteria are given in Appendix 1. The benchmark describes optimal movement, with good joint alignment, as opposed to ‘normal’ movement.

The HLLMS tests have been prioritised in order of relevance determined by the reliability and validity of the HLLMS, as indicated in Table 1. A mini- screen of Tests 1 to 3 can be performed when time is restricted to perform the whole HLLMS.

2.1.1 Small Knee Bend (SKB) Test

Purpose: Why the test was chosen?

- This test is regularly used to identify individuals at risk of musculoskeletal (MSK) injuries to develop targeted exercise interventions and reduce potential risk [105].
- PFP is associated to greater peak hip adduction, internal rotation and contralateral pelvic drop and dynamic valgus index when compared with healthy people [72, 96, 105].
- FAIS individuals show altered movement, including squatting slower with less peak hip adduction [62], increased hip flexion and anterior pelvic tilt [61] compared to healthy controls.
- Poor control of hip and knee alignment (in particular uncontrolled hip medial rotation and knee valgus), as well as studies where poor control of pelvic tilt and rotation was associated with higher lower extremity injury risk [36-38]. The validity of this test manoeuvre was demonstrated by recordings of participants who graded poor on the single leg squat test exhibited weaker and slower muscle activation of the hip abductors than participants graded as good performers, therefore identifying hip muscle dysfunction [30].
- The purposes of the test are to assess the ability to maintain balance, postural control, and lower body alignment [30], and the ability to actively dissociate and control hip flexion and medial rotation [26 pg 426, 457, 459].
- See Appendix 1 (Test 1) for the optimal starting position and benchmark description criteria as illustrated in Figure 1.

2.1.2 Standing Hip Flexion Test (flex 0-110°)

Purpose: Why the test was chosen?

- Poor control is associated with dysfunction of the hip abductor muscles on both the stance and moving leg [70].
- Altered hip control of increased contralateral pelvic hike (hitch) is associated with increased risk of acute non-contact knee injuries and anterior cruciate ligament (ACL) injuries [60]
- This is a test of specific muscle recruitment/concentric activation of the hip flexor stabilisers (iliacus/pectineus) [7, 50 pg 180-184] and assesses the ability to actively dissociate and control hip lateral rotation/abduction [26 pg 472].
- See Appendix 1 (Test 2) for description and benchmark criteria, and Figure 2.

2.1.3 Hip Abductor Lateral Rotator Test

Purpose: Why the test was chosen?

- This test is conducted in side lying to assess trunk and pelvic control during active lower limb movement from an unstable position [73] and maintenance of neutral trunk and pelvic alignment in the frontal plane [32].
- Assesses ability to actively dissociate and control hip medial rotation.
- Poor control may be associated with reduced stabilising ability of the gluteal lateral rotators, especially deep posterior gluteus medius and deep gluteus maximus [26 pg 467]
- See Appendix 1 for the optimal starting position (Figure 3) and the benchmark description criteria (Test 3), as illustrated in Figure 4.

2.1.4 SKB with Trunk Rotation Test

Purpose: Why the test was chosen?

- The addition of trunk rotation to the SKB test assesses relative stiffness (restrictions) [90] of thoracolumbar rotation, while maintaining pelvic control [26 pg 454], as well as the ability to actively dissociate and control medial rotation and lateral rotation of the hip independently of trunk rotation [26 pg 457, 463, 475, 59], as described in Appendix 1 (Test 4) and illustrated in Figure 5.
- Sports involving actions such as tackling, kicking, catching, sprinting and change of direction require trunk rotation to facilitate the required movement task.
- Lumbo-pelvic movement dysfunction may be a cause of hamstring injuries, suggesting muscle imbalances increase the workload on the hamstring muscles by decreasing gluteus maximus muscle activation and increasing tensile stress on the biceps femoris muscle, both possibly affected by an anteriorly tilted pelvis[82].

2.1.5 Deep Squat Test

Purpose: Why the test was chosen?

- A competent squat pattern requires major joints of the lower body (i.e. foot, ankle, knee and hip) and the lumbar and thoracic spine to have adequate stability and mobility [91].
- This test assesses pelvic stability and function of the rectus femoris, hamstrings and hip abductor and adductor muscles [23, 91].
- Inability to perform a bodyweight squat at or below 90 degrees of knee flexion with balance, symmetry and control may imply generalised body stiffness or restricted joint mobility and/or stability within the kinetic chain [27, 28].

- Patients with FAIS demonstrated less squat depth and altered lumbo-pelvic kinematics, with smaller pelvic posterior tilt [7, 8, 58, 74].
- See Appendix 1 (Test 5) for description and benchmark criteria, and Figure 6.

2.2 Scoring of the HLLMS

A scoring system is used to grade the quality of movement observed during the test procedures, according to criteria that define deviations of the body segments from the benchmark (optimum), by assessing the presence or absence of a deviation. Deviations from the benchmark criteria indicate poor movement control. Each benchmark criterion is rated in response to a question, as detailed in Appendix 1, which is based on the specific movement quality of one or more joints on a dichotomous scale, rated as 'yes', meaning that the movement fault is present, or 'no', meaning that the movement fault is absent. The five HLLMS tests include a total of 21 yes or no questions.

The total score can be used as an outcome measure to demonstrate changes in overall movement quality over time in response to interventions but must be used with caution. The total score of a movement screen assumes movement control ability to be unidimensional [52] and may be misleading relative to the individual item scores. It has been proposed that individual movement patterns are more informative than the summed scores [52]. For the purposes of the HLLMS, individual criteria scores are likely to be more informative than summed scores for directing intervention strategies to enable targeting of the weakest movement patterns, which cannot be identified from the summed scores.

2.3 Reliability testing - participants and data collection procedure

Recreational footballers, aged 16-19 years, were recruited using convenience sampling from clubs in the South Central region of England. Clubs were included if they carried out at least two training sessions a week in addition to matches played or practiced two to five times a week and played 15-30 matches during the season. Player exclusion criteria were: playing professional football, being injured and unable to take part in football, lumbar spine pathology, neurological or systemic disorders, bone or joint problems or any condition preventing full participation in all organised football activities. Players were defined as injured until they were fully fit to take part in all types of training and matches [101], at which point they were eligible for inclusion into the study.

The sample sizes necessary for reliability studies vary in the literature, but it has been suggested that for a true *p* of 0.7 against an alternative *p* 1 of 0.9, based on a 5% significance level and a power of 80% (beta=0.20) for two raters or two time points, 19 participants are needed [104]. Similarly, Atkinson et al [5] suggested 20 participants as sufficient. Previous studies using movement control tests have used 20 subjects [67, 86, 100]; thus n=20 was considered acceptable for the present intra and inter-reliability studies.

2.3.1 Intra-rater reliability: Twenty participants were recorded during the HLLMS using a digital video camera (Sony handycam HDR CX280E, 8.9 megapixels, 1080 Full HD, MP4) mounted on a tripod. The participants were recorded from both the anterior and lateral view to capture different movement faults from different angles. The investigator (NB) rated the movement patterns on two occasions, nine days apart [43, 99, 106] using the HLLMS scoring criteria described in the previous section. A minimum of a week between the ratings was used to minimise the potential for the rater to remember the testing scores from session one [55, 63]. Also, to further minimise potential test-retest bias and the rater recalling scores from session one, the order of rating the videos was changed for session two. The rater was permitted to watch the videos as many times as necessary and at a speed that was needed to score each test.

2.3.2 Inter-rater reliability: A total of 34 participants were screened by one researcher (Rater 1) and examined for inter-rater reliability. Fourteen participants were screened by Rater 1 (NB) and Rater 2 (CL), while a further 20 participants were screened by rater 1 (NB) and Rater 3 (DW) simultaneously in real-time to establish inter-rater reliability. Rater 1 (NB) had 12 years' MSK experience, four years skilled in movement control assessment (predominantly using the HLLMS) and attended the FMS course. Rater 2 (CL) had 16 years' MSK experience, one month using the HLLMS but seven years using movement control assessments. Rater 3 (DW) had five years' MSK experience, three months using movement control assessment with no prior use of the HLLMS. Both Rater 1 & 3 attended The Performance Matrix: Movement and Performance Screening course.

2.4 Statistical Analysis

Cohen's Kappa [24, 25] is commonly used to assess reliability of movement screening [1, 31, 67, 89] but there are well documented statistical problems associated with the measure [20, 22, 40, 67]. Kappa is affected by small numbers for some criteria, despite high Percentage Agreement (PA), leading to the paradox of Kappa [22]. Therefore, to attempt to adjust overall PA for chance agreement and avoid the paradox of Kappa, to assess the level of intra- and inter-rater reliability for the observational rating of the HLLMS, the PA and the First Order Coefficient (AC1) proposed by

Gwet [46] were used for analysis. The AC1 statistic adjusts the overall probability based on the chance that raters may agree on a rating, despite raters giving a random value [20, 46]. AC1 was calculated using Gwet's AC1 formula [112]. The scale used by McHugh [65] to interpret Kappa was used in the present study to interpret AC1 values, as the two types of values are considered to be similar, as highlighted by Gwet [46]. The categories of the scale were: 0-0.20 None; 0.21-0.39 Minimal; 0.40-0.59 Weak; 0.60-0.79 Moderate; 0.80-0.90 Strong; > 0.90 Almost perfect [65].

3. RESULTS

The intra-rater reliability for the HLLMS was almost perfect, with an overall mean PA of 96%, ranging from 94% during the SKB test to 98% in the deep squat test (Table 2). The AC1 overall mean agreement value for the screen was 0.93, ranging from 0.90 during the SKB test to 0.96 in the deep squat test (Table 2). The overall inter-rater reliability (n=34) for the HLLMS was strong, with an overall mean PA of 88% and AC1 of 0.82. The inter-rater reliability for Rater 1 & Rater 2 (n=14) was almost perfect, with PA values ranging from 64 to 100% (mean 93%) (Table 3). While AC1 scores show strong agreement between Rater 1 & Rater 2 with an overall mean of 0.89 (Table 3). The inter-rater reliability scores for Rater 1& Rater 3 three (n=20) were lower than Rater 1 & Rater 2 (n=14), with an overall PA of 83% and AC1 value of 0.74 (Table 4), indicating strong and moderate agreement respectively.

4. DISCUSSION

The HLLMS has been described in detail and shown to have almost perfect intra-rater reliability and strong inter-rater reliability in adolescent male footballers. The HLLMS differs from previous movement screens, as it tests hip control in isolation and poor control indicates that the hip joint is vulnerable to abnormal loading. Whilst the HLLMS uses some well established test manoeuvres, its novelty is the combination of tests and the specific assessment of movement quality against benchmark criteria for all segments of the lower limbs.

The present reliability results compare favourably with those of other movement screens. The intra-rater percentage agreement results were similar to those for the Foundation Matrix tested in adults, which found excellent overall percentage agreement for a very experienced rater (97.5%; ranging from 87.5 to 100%) and a less experienced rater (93.9%; 75-100%) [67]. The inter-rater reliability by the Foundation Matrix screening tool was also similar to the present study results with an overall mean PA of 87% (range 68-100%) [67]. Whatman et al [108] demonstrated a mean intra-rater agreement for 26 physiotherapists rating a bilateral SKB, drop jump and single leg SKB were substantial for all tests (PA: 79-88%; AC1: 0.60-0.78), which were lower than the present study but included novice raters.

Higher inter-rater agreement shown between Rater 1 vs Rater 2 and between Rater 1 vs Rater 2 may also reflect the experience of the raters. Both physiotherapist Raters 1 and 2 had 12 and 16 years MSK experience, with additional four and six years of movement screening experience, respectively. Physiotherapist Rater 3 only had five years' MSK with three months of movement screening experience. There is some evidence that inter-rater agreement improves with experience[108]. When observing gait, experienced therapists showed higher levels of inter-rater agreement with less variation between ratings [19]. Furthermore, Von Porat et al [103] have shown that knee movement pattern quality can be observed reliably by experienced physiotherapists (ICC 0.57-0.76; p=0.001-0.032) who have undergone prior training, while low levels of agreement (κ=0.16-0.28) were reported for novice athletic trainers rating a single leg squat [34]. In contrast, Smith et al [100] and Gulgin et al [45] suggested the level of the raters' experience did not influence the inter-rater reliability. However, Whatman et al [108] reported the lowest inter-rater agreement (AC1: 0.32-0.47) in the group of physiotherapists with less than five years' experience. Therefore, the higher inter-rater (Rater 1 vs Rater 2) and intra-rater results in the present study supports the claim that reliability can improve with experience [108], so the influence of experience using the HLLMS needs to be explored more comprehensively to establish the generalisability of the tool.

In the abovementioned and present study, individual test manoeuvres were examined separately for reliability, whereas the total scores were used for examining the reliability of the FMS, which has shown good intra-rater reliability (Intraclass correlation coefficient=0.87; 95% CI=0.79-0.92) from a systematic review with meta-analysis [31]. Using total scores as opposed to individual item scores in reliability analysis of movement screens may be misleading, as it is not possible to identify poor reliability of specific test criteria, as highlighted by Mischiati et al [67]. A practical implication is that functional limitations that need addressing clinically may be missed [79].
. Inter-rater reliability was classified as strong and has since been found to be acceptable in other cohorts using the HLLMS, including golfers and military personnel (in preparation). Both Rater 2 (CL) and Rater 3 (DW) had little experience and training using the HLLMS before testing inter-rater reliability, which may have affected their ratings. However, limited training and experience may reflect real-world setting, where time and resources may be restricted.

Two aspects of validity of the observational ratings made using the HLLMS have been examined: comparison with a gold standard (criterion validity) and sensitivity to change. A case study showed observational ratings from the SKB and SKB with trunk rotation tests were supported by kinematics measures using 3-D motion analysis [111]. The case study also assessed the ability of the HLLMS to detect change over time [111]. Larger studies to examine both these aspects are in progress.

Post-traumatic OA is increasingly recognised as a burden in young adults and modifiable, through early detection and intervention for secondary prevention [109]. There is evidence that movement impairments at the hip and pelvis may trigger injuries such as anterior cruciate ligament tears [49], iliotibial band syndrome [76], and patellofemoral joint pain [84]. Therefore, improvement in movement control at the hip and/or pelvis may help prevent injuries more distally in the kinetic chain. The HLLMS has a potential role to play in identifying poor movement control for primary prevention of injuries prior to participation in sports, training and competition [94] and secondary prevention of post-traumatic OA for all lower limb segments.

Current movement screens in the literature include the FMS [54], nine test screening battery [42], the foundation matrix [67, 71], landing error scoring system (LESS) [80], soccer injury movement screen (SIMS) [64], and netball movement screening tool (NMST)[85], which have mainly focused on predicting injury risk [11, 110]. Existing movement screening tools do not specifically focus on hip movement patterns or considers the impact of motor control exercises on hip and pelvic movement quality, which may help prevent or manage hip, groin and lower limb pain and dysfunction. However, preliminary observations using components of the HLLMS suggest the tests can detect movement control impairments [17]. For example, inability to control hip flexion and medial rotation has been demonstrated in young academy footballers [15] and adult professional golfers [16].

The intended purpose of the HLLMS to inform targeted exercise interventions, as has been illustrated in a proof of concept case study [111]. For example, the observed movement faults indicating poor hip flexion control can be associated with increased trunk flexion and anterior pelvic tilt [15, 17, 111]. Also, increased anterior pelvic tilt have been noted in individuals with FAIS compared to healthy controls [6, 61] and is suggested to relate to altered hip extensor muscle strength/activation[7, 88]. These faults therefore indicate exercises targeting gluteus maximus, e.g. bilateral bridge, unilateral bridge, hip extension in quadruped on elbows with the knee extended or flexed and a forward lunge with an upright trunk [97]. This suggestion is supported by the case study of a young footballer with hip pain showing improved symptoms, and movement control of the trunk and pelvis, following a motor control exercise programme informed by the HLLMS [111]. Similarly, some movement screening tools have a secondary objective to guide individual and corrective exercise recommendations from findings of poor movement quality[11]. Examples include the following five movement screening tools: the FMS [28], athletic ability assessment (AAA)[66], modified 4 movement screen (M-4 MS)[68], conditioning specific movement tasks (CSMT)[83] and the foundation matrix[67] , but these movement screens do not specifically focus on the hip and lower limb.

With the increasing aging population worldwide and the growing incidence of people with OA requiring treatment, the need to find modifiable factors to influence the disease process is crucial. The HLLMS could potentially identify modifiable movement compensations and direct referral for primary, secondary and tertiary prevention, defined in the context of injury and OA as follows:

- Primary prevention to protect healthy people from developing or experiencing an injury through risk reduction strategies.

- Secondary prevention to prevent re-injury or overuse to avoid progression to OA or halting/slowing the progression of OA in its early stages.
- Tertiary prevention to guide management of OA and reduce its impact on function, joint longevity, delaying or preventing joint surgery, and improve quality of life.

Interest in the HLLMS following presentation at conferences [15, 16] has generated collaborative international projects where the potential for various applications of the screening tool are being explored in different settings and populations. Present and planned projects include examining primary, secondary and tertiary prevention strategies. Studies using the HLLMS to prescribe exercise programmes to improve movement quality to protect hips and lower limb joints are being conducted in young recreational football and rugby players, professional footballers, ballet dancers and military personnel. Another study aims to examine whether the HLLMS can be used to stratify patients for conservative management of symptomatic hip and knee OA and another study is using the HLLMS in patients with hip-related pain in an orthopaedic setting. In addition, a modified HLLMS is being used in the hip and knee OA study, as not all the benchmark criteria are suitable for older symptomatic people. The present paper forms the basis for these studies exploring clinical and field applications. It may transpire that the tests and / or benchmark criteria within the HLLMS will require adaptations for specific sporting or occupational groups and all five tests may not be needed for each scenario.

5. CONCLUSIONS

The present paper describes the HLLMS to identify poor movement quality and its reliability for testing young community footballers has been demonstrated. The HLLMS is simple and quick to use, and focusses on identifying specific deviations from benchmark criteria for optimal hip and lower limb movement control. The intention is to use the outcome of the movement quality assessment to inform targeted motor control exercises. Several potential applications of the HLLMS are being explored in various cohorts of different ages and physical activity to examine the utility of the screen for assessing movement quality and informing exercise interventions to improve movement control.

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CONFLICT OF INTEREST STATEMENT

Sarah Mottram is an employee of and Mark Comerford is a consultant to Comera Movement Science Ltd. who educate and train sports, health, and fitness professionals to better understand, prevent, and manage musculoskeletal injury and pain that can impair movement and compromise performance in their patients, players, and clients. No other authors have any conflicts of interests to declare. No financial support or equities were provided by Movement Performance Solutions Ltd.

Submission Statement

We represent that this submission is original work, and is not under consideration for publication with any other journal.

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Figures, Tables and Appendix Legends

Figure 1. SKB test (A) lateral view (B) frontal view

Figure 2. Standing hip flexion test (flex 0-110°)

Figure 3. Optimal starting alignment for hip abductor stabiliser tests

Figure 4. Hip abductor lateral rotator test (A) posterior view (B) superior view

Figure 5. SKB with trunk rotation test to the right and left

Figure 6. Deep squat test

Table 1. Priority order of the HLLMS tests

Table 2. Table 2. Summary of the intra-rater reliability (means and ranges) for percentage agreement and AC1 for the HLLMS tests in young male recreational footballers (n=20)

Table 3. Table 3. Summary of inter-rater reliability (means and ranges) for percentage agreement and AC1 for the HLLMS tests in young male recreational footballers (n=14) between Rater 1 and Rater 2

Table 4. Summary of inter-rater reliability (means and ranges) for percentage agreement and AC1 for the HLLMS tests in young male recreational footballers (n=20) between Rater 1 and Rater 3

Appendix 1. Benchmark descriptions, observed movement patterns and questions for the observer (criteria against benchmark) for the 5 tests of the Hip and Lower Limb Movement Screen

Table 1. Priority order of the HLLMS tests

Number	Tests
1	Small knee bend (SKB)
2	Standing hip flexion to 110°
3	Hip abduction with lateral rotation
4	SKB with trunk rotation
5	Deep squat

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Table 2. Summary of the intra-rater reliability (means and ranges) for percentage agreement and AC1 for the HLLMS tests in young male recreational footballers (n=20)

Test	% Agreement mean (range)	AC1 mean (range)
Small knee bend	94 (85-100)	0.90 (0.71-1.00)
Standing hip flexion 0-110°	96 (85-100)	0.91 (0.73-1.00)
Hip abduction with lateral rotation	96 (90-100)	0.95 (0.87-1.00)
Small knee bend with trunk rotation	96 (90-100)	0.94 (0.84-1.00)
Deep squat	98 (95-100)	0.96 (0.91-1.00)
Overall mean agreement	96 (85-100)	0.93 (0.71-1.00)

%= percentage, °= degrees

Table 3. Summary of inter-rater reliability (means and ranges) for percentage agreement and AC1 for the HLLMS tests in young male recreational footballers (n=14) between Rater 1 and Rater 2

Test	% Agreement mean (range)	AC1 mean (range)
Small knee bend	90 (69-100)	0.86 (0.43-1.00)
Standing hip flexion 0-110°	89 (64-100)	0.78 (0.37-1.00)
Hip abduction with lateral rotation	88 (79-100)	0.85 (0.66-1.00)
Small knee bend with trunk rotation	97 (86-100)	0.96 (0.81-1.00)
Deep squat	100 (100-100)	1.00 (1.00-1.00)
Overall mean agreement	93 (64-100)	0.89 (0.37-1.00)

%= percentage, °= degrees

Table 4. Summary of inter-rater reliability (means and ranges) for percentage agreement and AC1 for the HLLMS tests in young male recreational footballers (n=20) between Rater 1 and Rater 3

Test	% Agreement mean (range)	AC1 mean (range)
Small knee bend	85 (70-100)	0.75 (0.48-1.00)
Standing hip flexion 0-110°	81 (65-95)	0.69 (0.41-0.95)
Hip abduction with lateral rotation	88 (75-100)	0.86 (0.68-1.00)
Small knee bend with trunk rotation	80 (60-100)	0.68 (0.31-1.00)
Deep squat	80 (80-80)	0.65 (0.63-0.66)
Overall mean agreement	83 (60-100)	0.74 (0.31-1.00)

%= percentage, °= degrees

A **B**

Benchmark Description: The individual stands on one leg by flexing the unsupported knee to 90°, hip at 0º with the thigh aligned in neutral, so the foot is behind the body [4]. The 2nd metatarsal of the weight bearing foot is aligned along the 10° neutral line of weight transfer to ensure correct foot position [5 pg 456]. The pelvis is maintained level and the trunk positioned vertical. The participant is instructed to bend their weight bearing knee slightly, while keeping the heel on the floor, which dorsi-flexes the ankle [2]. During the SKB test the body weight must be kept on the heel rather than the ball of the foot. The line of the femur is on the 10° neutral line of weight transfer and the knee aligns over the 2nd metatarsal.

FIGURE 1. SKB test (A) lateral view (B) frontal view

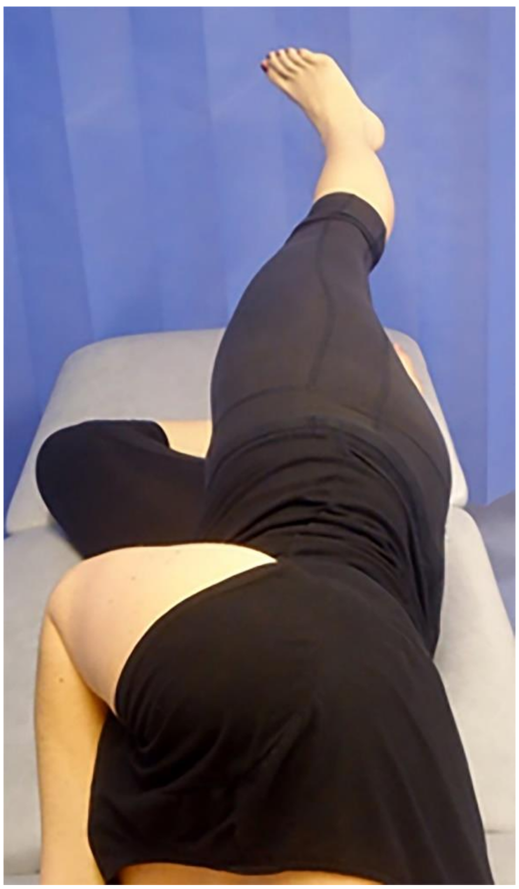
Benchmark Description: The individual stands with their feet hip width apart and toes pointing forward with the arms across the chest. While keeping the pelvis level, the trunk vertical and the weight-bearing knee in neutral, the opposite hip is flexed up to 110° while flexing the knee.

FIGURE 2. Standing hip flexion test (flex 0-110°)

Benchmark Description: The participant is in side lying with the pelvis and spine in neutral alignment, and the underneath leg flexed for support. The uppermost leg is extended and supported horizontally, with the hip extended, as far as no lumbar extension or anterior pelvic tilt occur.

FIGURE 3. Optimal starting alignment for hip abductor stabiliser tests

A 

B 

Benchmark Description: In the uppermost leg, the hip is laterally rotated (50% of maximum range) and then lifted actively towards the ceiling into hip abduction to 45°.

FIGURE 4. Hip abductor lateral rotator test (A) posterior view (B) superior view

The benchmark position for the SKB with trunk rotation follows the same protocol as the SKB test, then the individual rotates the shoulders and upper trunk around to one side and then the other side, without moving the pelvis, which remains facing forwards. There should be symmetrical rotation of the thoracic spine to both sides with the hip and pelvis remaining in neutral. At least 30° of thoracic rotation should be achieved.

FIGURE 5. SKB with trunk rotation test to the right and left

Benchmark Description: The individual stands with their feet shoulder width apart, arms forward and feet with the 2nd metatarsals aligned along the 10° neutral line of weight transfer [5 pg 456]. The deep squat is performed by flexing the knees and dorsi-flexing the ankles while keeping the heels on the floor, keeping bodyweight on the heels. The lines of the femurs should be horizontal with the floor while the knees align to the 2nd metatarsals. The trunk is maintained vertical or parallel with the tibiae.

FIGURE 6. Deep Squat test

Appendix 1. Benchmark descriptions, observed movement patterns and questions for the observer (criteria against benchmark) for the 5 tests of the Hip and Lower Limb Movement Screen

<table>
<tr><th colspan="2">Test 1: Small Knee Bend (SKB) test</th></tr>
<tr><td colspan="2">Benchmark Description: The individual stands on one leg by flexing the unsupported knee to 90°, hip at 0° with the thigh aligned in neutral, so the foot is behind the body [4]. The 2nd metatarsal of the weight bearing foot is aligned along the 10° neutral line of weight transfer to ensure correct foot position [5 pg 456]. The pelvis is maintained level and the trunk positioned vertical. The participant is instructed to bend their weight bearing knee slightly, while keeping the heel on the floor, which dorsi-flexes the ankle [2]. To standardise the amount of flexion relative each individual, a piece of tape is placed on the floor in a T-shape. The individual stands with the long axis of the foot aligned to the stem of the T; the 2nd toe placed on the stem. The individual is then asked to bend the knee, without bending forward from the hips, until he/she can no longer see the top bar of the T-shape along the toes (corresponding to more than 2 cm over the 2nd metatarsal or approximately 50° of knee flexion) [1, 3]. During the SKB test the body weight must be kept on the heel rather than the ball of the foot. The line of the femur is on the 10° neutral line of weight transfer and the knee aligns over the 2nd metatarsal (Figure 1) [3]. Movement patterns are observed while the test is performed; answering the appropriate questions.</td></tr>
<tr><td>Observed Abnormal Movement Patterns</td><td>Questions Scoring Criteria (Yes/No)</td></tr>
<tr><td>Benchmark distance – knee does not move more than 2 cm past the toes</td><td>Does the knee fail to move 2 cm past the toes?</td></tr>
<tr><td>Anterior pelvic tilt</td><td>Does the pelvis begin in, or move (rotate) forwards (anteriorly)?</td></tr>
<tr><td>Trunk leans forward</td><td>Does the trunk lean forwards (flex)?</td></tr>
<tr><td>Femoral adduction / medial rotation</td><td>Is there an increase in dynamic valgus from the start position?</td></tr>
<tr><td>Hip hitching/drop</td><td>Does the pelvis fail to stay level ?</td></tr>
</table>

Test 2: Standing hip flexion test (flex 0-110°)	
Benchmark Description: The individual stands with their feet hip width apart and toes pointing forward with the arms across the chest. While keeping the pelvis level, the trunk vertical and the weight-bearing knee in neutral, the opposite hip is flexed up to 110° while flexing the knee (Figure 2). Movement patterns are assessed against benchmark criteria by answering the appropriate questions.	
Observed Abnormal Movement Patterns	**Questions Scoring Criteria (Yes/No)**
Benchmark distance hip not move to 110° flexion	Does the hip fail to bend (flex) just beyond 90 degrees (approximate 110 degrees)?
Body leans backward	Does the trunk lean backwards (extend)?
Posterior pelvic tilt	Does the pelvis begin, or move (rotate) backwards (posterior)?
Knee flexed	Does the weight bearing knee bend (flex)?
Hip hitching/drop	Does the pelvis fail to stay level on the weight-bearing side?
Test 3: Hip Abductor lateral rotator test	
Benchmark Description: The participant is in side lying with the pelvis and spine in neutral alignment, and the underneath leg flexed for support. The uppermost leg is extended and supported horizontally, with the hip extended, as far as no lumbar extension or anterior pelvic tilt occur (Figure 3). In the uppermost leg, the hip is laterally rotated (50% of maximum range) and then lifted actively towards the ceiling into hip abduction to 45° (Figure 4). Movement patterns are observed and assessed against the benchmark criteria.	
Observed Abnormal Movement Patterns	**Questions Scoring Criteria (Yes/No)**
Benchmark distance hip not move to 45° abduction	Does the hip fail to abduct to 45 degrees?
Pelvic hitching	Does the pelvis fail to stay vertical (rotate up or down)?
Medial rotation hip	Does the leg loose upward (lateral) rotation?
Flexion hip	Does the hip/knee (leg) move forward flexion?

Rotation pelvis backwards or forwards	Does the pelvis fail to stay vertical (rotate backwards or forwards)?
Test 4: SKB with trunk rotation test	
Benchmark Description: The benchmark position for the SKB with trunk rotation follows the same protocol as the SKB test, then the individual rotates the shoulders and upper trunk around to one side and then the other side, without moving the pelvis, which remains facing forwards (Figure 5). There should be symmetrical rotation of the thoracic spine to both sides with the hip and pelvis remaining in neutral. At least 30° of thoracic rotation should be achieved. Movement patterns are observed against benchmark criteria, answering the appropriate questions.	
Observed Abnormal Movement Patterns	**Questions Scoring Criteria (Yes/No)**
Benchmark distance trunk rotation < 30°	Does the trunk rotate less than 30 degrees?
Hip hitching/drop	Does the pelvis fail to stay level?
Hip and pelvis rotation to follow trunk	Does the pelvis follow the trunk rotation?
Trunk flexion	Does the trunk lean forwards (flex)?
Test 5: Deep squat test	
Benchmark Description: The individual stands with their feet shoulder width apart, arms forward and feet with the 2nd metatarsals aligned along the 10° neutral line of weight transfer [5 pg 456]. The deep squat is performed by flexing the knees and dorsi-flexing the ankles while keeping the heels on the floor, keeping bodyweight on the heels. The lines of the femurs should be horizontal with the floor while the knees align to the 2nd metatarsals. The trunk is maintained vertical or parallel with the tibiae (Figure 6). Movement patterns are assessed against the benchmark criteria.	
Observed Abnormal Movement Patterns	**Questions Scoring Criteria (Yes/No)**
Benchmark distance femur not horizontal	Does the thigh (femur) fail to reach horizontal with the floor?
Trunk leans forward	Does the trunk fail to stay parallel with the shin (tibia)?

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