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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

1 **ABSTRACT**

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

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

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

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

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

22

23 **KEYWORDS:** Young Footballers, Movement Patterns, Movement Screening Tool

24 1. INTRODUCTION

25 Joint damage, whether due to a single traumatic injury or to repetitive abnormal loading, can
26 contribute to osteoarthritis (OA), which is a substantial cause of disability. Knee injury is the
27 classic example of a traumatic event increasing the risk of OA. Prospective studies report a 10-
28 fold increased risk of developing knee OA 12-20 years post-injury compared with an uninjured
29 population⁸⁷. At the hip, cam morphology of the femur, which is an asphericity of the femoral
30 head, also has an increased risk of later hip OA². For cam morphology, however, it is not a
31 single traumatic event that contributes to the increased risk. Instead, altered joint loading^{7, 75, 92} is
32 thought to be the primary driver of hip OA in this young population.

33
34 For both post-traumatic OA¹⁰⁹ and OA due to altered loading¹⁰, young sporting people are at
35 increased risk. Post-traumatic OA is recognised as an increasing burden in young adults^{4, 109}.
36 Cam morphology itself is thought to result from vigorous sports activity during the critical stages
37 of skeletal development^{3, 81}. However, not all individuals with cam morphology develop
38 femoroacetabular impingement syndrome (FAIS), which is the triad of symptoms, morphology,
39 and clinical signs⁴⁴. Altered movement at the hip is likely a contributing factor not only to the
40 morphology but also to the onset of symptoms.

41
42 Reducing in the risk of future OA is important both because of the economic burden of the
43 disease and the negative impact on quality of life¹⁸. Strategies to prevent OA or delay its
44 progression through identifying modifiable factors, such as abnormal movement patterns^{10, 12}
45 may help reduce the impact of OA. Movement screening tools have gained popularity in the
46 clinical setting to predict injury risk and/or guide injury prevention programmes²¹. Kiesel et al⁵³

47 suggested that range of motion (ROM) and strength measurements are not able to measure
48 fundamental changes in motor control following injury. Movement screening tests are
49 comprehensive and challenge components of ROM, muscle strength and flexibility but also
50 coordination, proprioception and motor control of multiple body regions, which can be assessed
51 at the same time by observing movement quality, defined as optimal motor control and joint
52 alignment^{28, 29, 57, 90, 91, 95}. Therefore, whole body tasks to assess changes in motor control are
53 considered better than traditional measurements such as ROM and strength⁵³. Tests to evaluate
54 movement control, termed “movement screening”, have been recommended to assess movement
55 quality to identify altered kinematics in the belief that this is linked to injury risk and peak
56 performance¹⁰⁷, and are considered important to identify dysfunction or abnormal movement
57 patterns⁴¹.

58
59 Identifying, addressing and defining movement is complex due to limited understanding of the
60 most efficient movement⁷⁸. However, movement screening tools to assess movement quality
61 involve qualitative identification and rating of movement compensations, asymmetries,
62 impairments and inefficiency of movement control¹¹⁰ and can be evaluated with tests in which a
63 person is asked to cognitively control movement at a specific joint (e.g. hip) while moving an
64 adjacent joint^{17, 26, 35}. Identified movement compensations, asymmetries, impairments and
65 inefficiency of movement control may lead to a disturbance or abnormality in the movement
66 system. In turn this may cause a loss of movement precision, contributing to repeated stresses to
67 tissue, alterations in control strategies and mechanical overload^{28, 77, 91}, possibly leading to pain
68^{48, 51}.

69

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

77
78 Existing movement screens lack specific focus on assessing control of the hip, pelvis and lower
79 limb joints. Samar et al ⁹³ proposed that the FMS is not appropriate for assessing hip dysfunction,
80 as it does not correlate with the Timed 6-m Hop and Triple Hop Distance tests, which are tools to
81 assess hip dysfunction. Also, the FMS has no unilateral weight-bearing test, which is a common
82 task needed in daily functions or sports ⁹ and more likely to highlight movement compensations
83 than bilateral tasks⁶². To address this problem of lack of focus on hip control, the Hip and Lower
84 Limb Movement Screen (HLLMS) was developed to assess movement quality. The purpose of
85 this screen is to inform exercise programmes to maintain lower limb joint health by ensuring
86 good alignment and preventing abnormal loading on joints. Such interventions aim to prevent
87 damage that could lead to OA or for secondary prevention of OA post-trauma ⁴. The present
88 paper describes the battery of movement tests comprising the HLLMS, examination of its intra-
89 and inter-rater reliability using the model of young male footballers, and potential applications in
90 various cohorts, sports and occupations.

91

92

93 **2. METHODS**

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

99

100 ***2.1 Development and Description of the HLLMS Tool***

101 The incidence of FAIS provides a useful model for developing OA prevention programmes, as
102 retired professional players have higher incidence of hip OA and total hip replacement surgery
103 than the general population^{98,102}. The HLLMS was first developed for young professional
104 footballers to characterise their movement faults^{15,17}. Current literature and input from
105 collaborating experts were used to develop optimal benchmark criteria for the HLLMS. The
106 benchmark criteria were developed to challenge the hip and lower limb to exaggerate the
107 movement compensations for an active population, possibly indicating hip and/or lower limb
108 dysfunction^{32,56,60,73,105}. For example, movement disorders exist in people with FAIS, showing
109 smaller squat depth⁵⁶ and reduced posterior pelvic tilt^{8,58}, ipsilateral trunk lean and pelvic rise
110 towards the symptomatic hip³³, greater hip flexion and anterior pelvic tilt⁶¹ and greater peak
111 trunk flexion angles⁴⁷. Also, patellofemoral pain (PFP) has been associated with an increased
112 peak hip adduction, internal rotation, contralateral pelvic drop and dynamic valgus index^{72,96,105}.
113 These movement abnormalities relate to the criteria used in the HLLMS of anterior pelvic tilt,
114 trunk leaning forward, femoral adduction/medial rotation (dynamic valgus), hip hitching/drop
115 and posterior pelvic tilt. Preliminary findings from professional young footballers showed

116 restricted internal hip rotation and poor movement control of hip flexion and medial rotation ^{15, 17},
117 in one or more criteria compared to the benchmark, indicating movement faults in the HLLMS
118 were: increased hip flexion, trunk leaning forwards, hips swaying back, femoral line moving
119 medially, hip hitching and hip or pelvis rotation following the trunk ^{15, 17}. The HLLMS was then
120 applied to recreational footballers and refined after preliminary feasibility and reliability testing,
121 to produce the current screen, for which preliminary intra- and inter-rater reliability testing is
122 described in the present paper. The screen is currently being tested in other cohorts, as outlined
123 later in the discussion.

124
125 Although the movement screening tool focuses on hip and pelvic control, it also evaluates distal
126 lower limb movements and is thus termed the HLLMS. The screen comprises five tests that can
127 be performed in the clinic or field environment that do not require equipment. During the test
128 manoeuvres, the rater observes the quality of the movement against benchmark criteria, by
129 assessing the presence or absence of a deviation using a yes/no dichotomous scale, taking
130 approximately 15 minutes to complete all the tests. The origins of each test and their purpose in
131 the context of the HLLMS are given below. The test description and benchmark assessment
132 criteria are given in Appendix 1. The benchmark describes optimal movement, with good joint
133 alignment, as opposed to ‘normal’ movement.

134
135 The HLLMS tests have been prioritised in order of relevance determined by the reliability and
136 validity of the HLLMS, as indicated in Table 1. A mini- screen of Tests 1 to 3 can be performed
137 when time is restricted to perform the whole HLLMS.

138
139

140 **2.1.1 Small Knee Bend (SKB) Test**

141 ***Purpose: Why the test was chosen?***

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

159

160

161

162

163 **2.1.2 Standing Hip Flexion Test (flex 0-110°)**

164 ***Purpose: Why the test was chosen?***

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

174

175 **2.1.3 Hip Abductor Lateral Rotator Test**

176 ***Purpose: Why the test was chosen?***

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

185

186 **2.1.4 SKB with Trunk Rotation Test**

187 ***Purpose: Why the test was chosen?***

- 188 • The addition of trunk rotation to the SKB test assesses relative stiffness (restrictions)⁹⁰ of
189 thoracolumbar rotation, while maintaining pelvic control^{26 pg 454}, as well as the ability to
190 actively dissociate and control medial rotation and lateral rotation of the hip
191 independently of trunk rotation^{26 pg 457, 463, 475, 59}, as described in Appendix 1 (Test 4) and
192 illustrated in Figure 5.
- 193 • Sports involving actions such as tackling, kicking, catching, sprinting and change of
194 direction require trunk rotation to facilitate the required movement task.
- 195 • Lumbo-pelvic movement dysfunction may be a cause of hamstring injuries, suggesting
196 muscle imbalances increase the workload on the hamstring muscles by decreasing gluteus
197 maximus muscle activation and increasing tensile stress on the biceps femoris muscle,
198 both possibly affected by an anteriorly tilted pelvis⁸².

199

200 **2.1.5 Deep Squat Test**

201 ***Purpose: Why the test was chosen?***

- 202 • A competent squat pattern requires major joints of the lower body (i.e. foot, ankle, knee
203 and hip) and the lumbar and thoracic spine to have adequate stability and mobility⁹¹.
- 204 • This test assesses pelvic stability and function of the rectus femoris, hamstrings and hip
205 abductor and adductor muscles^{23, 91}.
- 206 • Inability to perform a bodyweight squat at or below 90 degrees of knee flexion with
207 balance, symmetry and control may imply generalised body stiffness or restricted joint
208 mobility and/or stability within the kinetic chain^{27, 28}.

209 • Patients with FAIS demonstrated less squat depth and altered lumbo-pelvic kinematics,
210 with smaller pelvic posterior tilt ^{7, 8, 58, 74}.

211 • See Appendix 1 (Test 5) for description and benchmark criteria, and Figure 6.

212

213 *2.2 Scoring of the HLLMS*

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

222

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

231

232 **2.3 Reliability testing - participants and data collection procedure**

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

242
243 The sample sizes necessary for reliability studies vary in the literature, but it has been suggested
244 that for a true p of 0.7 against an alternative p of 0.9, based on a 5% significance level and a
245 power of 80% (beta=0.20) for two raters or two time points, 19 participants are needed ¹⁰⁴.
246 Similarly, Atkinson et al ⁵ suggested 20 participants as sufficient. Previous studies using
247 movement control tests have used 20 subjects ^{67, 86, 100}; thus $n=20$ was considered acceptable for
248 the present intra and inter-reliability studies.

249
250 **2.3.1 Intra-rater reliability:** Twenty participants were recorded during the HLLMS using a digital
251 video camera (Sony handycam HDR CX280E, 8.9 megapixels, 1080 Full HD, MP4) mounted on
252 a tripod. The participants were recorded from both the anterior and lateral view to capture
253 different movement faults from different angles. The investigator (NB) rated the movement
254 patterns on two occasions, nine days apart ^{43, 99, 106} using the HLLMS scoring criteria described in

255 the previous section. A minimum of a week between the ratings was used to minimise the
256 potential for the rater to remember the testing scores from session one^{55,63}. Also, to further
257 minimise potential test-retest bias and the rater recalling scores from session one, the order of
258 rating the videos was changed for session two. The rater was permitted to watch the videos as
259 many times as necessary and at a speed that was needed to score each test.

260
261 *2.3.2 Inter-rater reliability:* A total of 34 participants were screened by one researcher (Rater 1)
262 and examined for inter-rater reliability. Fourteen participants were screened by Rater 1 (NB) and
263 Rater 2 (CL), while a further 20 participants were screened by rater 1 (NB) and Rater 3 (DW)
264 simultaneously in real-time to establish inter-rater reliability. Rater 1 (NB) had 12 years' MSK
265 experience, four years skilled in movement control assessment (predominantly using the
266 HLLMS) and attended the FMS course. Rater 2 (CL) had 16 years' MSK experience, one month
267 using the HLLMS but seven years using movement control assessments. Rater 3 (DW) had five
268 years' MSK experience, three months using movement control assessment with no prior use of
269 the HLLMS. Both Rater 1 & 3 attended The Performance Matrix: Movement and Performance
270 Screening course.

271
272 *2.4 Statistical Analysis*
273 Cohen's Kappa^{24,25} is commonly used to assess reliability of movement screening^{1,31,67,89} but
274 there are well documented statistical problems associated with the measure^{20,22,40,67}. Kappa is
275 affected by small numbers for some criteria, despite high Percentage Agreement (PA), leading to
276 the paradox of Kappa²². Therefore, to attempt to adjust overall PA for chance agreement and
277 avoid the paradox of Kappa, to assess the level of intra- and inter-rater reliability for the
278 observational rating of the HLLMS, the PA and the First Order Coefficient (AC1) proposed by

279 Gwet⁴⁶ were used for analysis. The AC1 statistic adjusts the overall probability based on the
280 chance that raters may agree on a rating, despite raters giving a random value^{20,46}. AC1 was
281 calculated using Gwet's AC1 formula¹¹². The scale used by McHugh⁶⁵ to interpret Kappa was
282 used in the present study to interpret AC1 values, as the two types of values are considered to be
283 similar, as highlighted by Gwet⁴⁶. The categories of the scale were: 0-0.20 None; 0.21-0.39
284 Minimal; 0.40-0.59 Weak; 0.60-0.79 Moderate; 0.80-0.90 Strong; > 0.90 Almost perfect⁶⁵.

285

286 **3. RESULTS**

287 The intra-rater reliability for the HLLMS was almost perfect, with an overall mean PA of 96%,
288 ranging from 94% during the SKB test to 98% in the deep squat test (Table 2). The AC1 overall
289 mean agreement value for the screen was 0.93, ranging from 0.90 during the SKB test to 0.96 in
290 the deep squat test (Table 2). The overall inter-rater reliability (n=34) for the HLLMS was strong,
291 with an overall mean PA of 88% and AC1 of 0.82. The inter-rater reliability for Rater 1 & Rater
292 2 (n=14) was almost perfect, with PA values ranging from 64 to 100% (mean 93%) (Table 3).
293 While AC1 scores show strong agreement between Rater 1 & Rater 2 with an overall mean of
294 0.89 (Table 3). The inter-rater reliability scores for Rater 1 & Rater 3 three (n=20) were lower
295 than Rater 1 & Rater 2 (n=14), with an overall PA of 83% and AC1 value of 0.74 (Table 4),
296 indicating strong and moderate agreement respectively.

297

298 **4. DISCUSSION**

299 The HLLMS has been described in detail and shown to have almost perfect intra-rater reliability
300 and strong inter-rater reliability in adolescent male footballers. The HLLMS differs from
301 previous movement screens, as it tests hip control in isolation and poor control indicates that the

302 hip joint is vulnerable to abnormal loading. Whilst the HLLMS uses some well established test
303 manoeuvres, its novelty is the combination of tests and the specific assessment of movement
304 quality against benchmark criteria for all segments of the lower limbs.

305
306 The present reliability results compare favourably with those of other movement screens. The
307 intra-rater percentage agreement results were similar to those for the Foundation Matrix tested in
308 adults, which found excellent overall percentage agreement for a very experienced rater (97.5%;
309 ranging from 87.5 to 100%) and a less experienced rater (93.9%; 75-100%)⁶⁷. The inter-rater
310 reliability by the Foundation Matrix screening tool was also similar to the present study results
311 with an overall mean PA of 87% (range 68-100%)⁶⁷. Whatman et al¹⁰⁸ demonstrated a mean
312 intra-rater agreement for 26 physiotherapists rating a bilateral SKB, drop jump and single leg
313 SKB were substantial for all tests (PA: 79-88%; AC1: 0.60-0.78), which were lower than the
314 present study but included novice raters.

315
316 Higher inter-rater agreement shown between Rater 1 vs Rater 2 and between Rater 1 vs Rater 2
317 may also reflect the experience of the raters. Both physiotherapist Raters 1 and 2 had 12 and 16
318 years MSK experience, with additional four and six years of movement screening experience,
319 respectively. Physiotherapist Rater 3 only had five years' MSK with three months of movement
320 screening experience. There is some evidence that inter-rater agreement improves with
321 experience¹⁰⁸. When observing gait, experienced therapists showed higher levels of inter-rater
322 agreement with less variation between ratings¹⁹. Furthermore, Von Porat et al¹⁰³ have shown
323 that knee movement pattern quality can be observed reliably by experienced physiotherapists
324 (ICC 0.57-0.76; p=0.001-0.032) who have undergone prior training, while low levels of
325 agreement (κ =0.16-0.28) were reported for novice athletic trainers rating a single leg squat³⁴. In

326 contrast, Smith et al ¹⁰⁰ and Gulgin et al ⁴⁵ suggested the level of the raters' experience did not
327 influence the inter-rater reliability. However, Whatman et al ¹⁰⁸ reported the lowest inter-rater
328 agreement (AC1: 0.32-0.47) in the group of physiotherapists with less than five years'
329 experience. Therefore, the higher inter-rater (Rater 1 vs Rater 2) and intra-rater results in the
330 present study supports the claim that reliability can improve with experience ¹⁰⁸, so the influence
331 of experience using the HLLMS needs to be explored more comprehensively to establish the
332 generalisability of the tool.

333
334 In the abovementioned and present study, individual test manoeuvres were examined separately
335 for reliability, whereas the total scores were used for examining the reliability of the FMS, which
336 has shown good intra-rater reliability (Intraclass correlation coefficient=0.87; 95% CI=0.79-0.92)
337 from a systematic review with meta-analysis ³¹. Using total scores as opposed to individual item
338 scores in reliability analysis of movement screens may be misleading, as it is not possible to
339 identify poor reliability of specific test criteria, as highlighted by Mischiati et al ⁶⁷. A practical
340 implication is that functional limitations that need addressing clinically may be missed ⁷⁹.

341 . Inter-rater reliability was classified as strong and has since been found to be acceptable in other
342 cohorts using the HLLMS, including golfers and military personnel (in preparation). Both Rater
343 2 (CL) and Rater 3 (DW) had little experience and training using the HLLMS before testing
344 inter-rater reliability, which may have affected their ratings. However, limited training and
345 experience may reflect real-world setting, where time and resources may be restricted.

346
347 Two aspects of validity of the observational ratings made using the HLLMS have been examined:
348 comparison with a gold standard (criterion validity) and sensitivity to change. A case study
349 showed observational ratings from the SKB and SKB with trunk rotation tests were supported by

350 kinematics measures using 3-D motion analysis ¹¹¹. The case study also assessed the ability of the
351 HLLMS to detect change over time ¹¹¹. Larger studies to examine both these aspects are in
352 progress.

353

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

362

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

373

374 The intended purpose of the HLLMS to inform targeted exercise interventions, as has been
375 illustrated in a proof of concept case study ¹¹¹. For example, the observed movement faults
376 indicating poor hip flexion control can be associated with increased trunk flexion and anterior
377 pelvic tilt ^{15, 17, 111}. Also, increased anterior pelvic tilt have been noted in individuals with FAIS
378 compared to healthy controls ^{6, 61} and is suggested to relate to altered hip extensor muscle
379 strength/activation^{7, 88}. These faults therefore indicate exercises targeting gluteus maximus, e.g.
380 bilateral bridge, unilateral bridge, hip extension in quadruped on elbows with the knee extended
381 or flexed and a forward lunge with an upright trunk ⁹⁷. This suggestion is supported by the case
382 study of a young footballer with hip pain showing improved symptoms, and movement control of
383 the trunk and pelvis, following a motor control exercise programme informed by the HLLMS ¹¹¹.
384 Similarly, some movement screening tools have a secondary objective to guide individual and
385 corrective exercise recommendations from findings of poor movement quality¹¹. Examples
386 include the following five movement screening tools: the FMS ²⁸, athletic ability assessment
387 (AAA)⁶⁶, modified 4 movement screen (M-4 MS)⁶⁸, conditioning specific movement tasks
388 (CSMT)⁸³ and the foundation matrix⁶⁷, but these movement screens do not specifically focus on
389 the hip and lower limb.

390
391 With the increasing aging population worldwide and the growing incidence of people with OA
392 requiring treatment, the need to find modifiable factors to influence the disease process is crucial.
393 The HLLMS could potentially identify modifiable movement compensations and direct referral
394 for primary, secondary and tertiary prevention, defined in the context of injury and OA as
395 follows:

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

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

402

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

417

418

419

420 **5. CONCLUSIONS**

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

429

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434

435 **CONFLICT OF INTEREST STATEMENT**

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

442

443 **Submission Statement**

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

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747

748 **Figures, Tables and Appendix Legends**

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

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

751 Figure 3. Optimal starting alignment for hip abductor stabiliser tests

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

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766 Screen

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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



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. 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



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 dorsiflexing 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

Test 1: Small Knee Bend (SKB) test	
<p>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.</p>	
Observed Abnormal Movement Patterns	Questions Scoring Criteria (Yes/No)
Benchmark distance – knee does not move more than 2 cm past the toes	Does the knee fail to move 2 cm past the toes?
Anterior pelvic tilt	Does the pelvis begin in, or move (rotate) forwards (anteriorly)?
Trunk leans forward	Does the trunk lean forwards (flex)?
Femoral adduction / medial rotation	Is there an increase in dynamic valgus from the start position?
Hip hitching/drop	Does the pelvis fail to stay level ?

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 lose 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	
<p>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.</p>	
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	
<p>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.</p>	
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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