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1 The association between fundamental athletic movements and physical fitness in elite junior
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18

19 Running Title: Movement skill and physical fitness testing

20 **Abstract**

21 This study investigated the associations between fundamental athletic movement and physical
22 fitness in junior Australian football (AF). Forty-four under 18 players performed a fundamental
23 athletic movement assessment consisting of an overhead squat, double lunge, single leg Romanian
24 deadlift, and a push up. Movements were scored on three assessment criteria using a three-point
25 scale. Additionally, participants performed five physical fitness tests commonly used for talent
26 identification in AF. A Spearman's nonparametric correlation matrix was built, with correlation
27 coefficients being visualised using a circularly rendered correlogram. Score on the overhead squat
28 was moderately positively associated with dynamic vertical jump height on left ($r_s = 0.40$; $P \leq 0.05$)
29 and right ($r_s = 0.30$; $P \leq 0.05$) leg take-off, stationary vertical jump ($r_s = 0.32$; $P \leq 0.05$), and negatively
30 associated with 20 m sprint time ($r_s = -0.35$; $P \leq 0.05$). Score on the double lunge (left / right side) was
31 moderately positively associated with the same physical fitness tests as well as score on the
32 multistage fitness test. Results suggest that improvements in physical fitness qualities may occur
33 through concurrent increases in fundamental athletic movement skill; namely the overhead squat
34 and double lunge movements. These findings may assist with the identification and development of
35 talent.

36

37 *Key words:* Motor competency; motor skill; performance testing; youth sport

38 **1. Introduction**

39 Given the difficulties associated with the attainment of sporting excellence, national sporting bodies,
40 federations, and team administrators often seek methods that enhance the efficiency of talent
41 development (Abernethy, 2008). One such method has been the implementation of talent
42 development programs that aim to facilitate the longitudinal skill progression of talent identified
43 juniors (Durand-Bush & Salmela, 2001). The premise of talent development programs is to minimise
44 performance differences between elite junior and senior competitions through the provision of a
45 superior learning environment (Vaeyens, Lenoir, Williams, & Philippaerts, 2008). Within Australian
46 football (AF), elite junior talent development programs are referred to as State Academies. Talent
47 identified juniors within these State Academies are exposed to high-level coaching, player welfare,
48 and sport and medical interventions, each of which is designed to prepare participants for the
49 rigours of elite senior AF (Burgess, Naughton, & Norton, 2012). Given these provisions, identification
50 onto a State Academy is crucial for juniors aspiring to be drafted into the Australian Football League
51 (AFL) (Robertson, Woods, & Gustin, 2015).

52 According to Vaeyens et al. (2008), talent identification can be defined as the recognition of superior
53 performance potential within a relatively homogenous athletic population. Despite this, common
54 methods proposed to be of assistance for talent identification in AF appears to only identify superior
55 current performance, which may not be indicative of long-term potential. Specifically, the use of
56 traditional physical outcome-oriented (e.g. speed or distance) fitness tests predominate the talent
57 identification literature in junior AF (Keogh, 1999; Woods, Raynor, Bruce, McDonald, & Collier,
58 2015). In part, this may be due to the physical requirements of AF game-play. For example, players'
59 at all developmental levels are required to combine intermittent anaerobic running efforts with
60 prolonged aerobic exercise during game-play (Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010).
61 Measuring these physical fitness qualities would therefore appear warranted. However, although
62 the use of such physical fitness tests may enable the identification of relatively superior physical
63 performers, their discrete nature may be more depictive of an acute performance 'snapshot' rather

64 than developmental potential (Vaeyens et al., 2008). Given their limited long-term predictive
65 capability, their isolated administration may result in talent misclassification (MacNamara & Collins,
66 2011), where players are overlooked given an inability to perform a physical fitness test at a high
67 standard at that current point in time. Thus, identifying certain attributes that may underpin the
68 development of physical fitness qualities may be of value to both talent recruiters and strength and
69 conditioning specialists, providing them with an indication of a juniors developmental potential.

70 Recently, Parsonage, Williams, Rainer, McKeown, and Williams (2014) reported associations
71 between fundamental athletic movement skills (defined as proficiency while performing movements
72 that commonly underpin conditioning exercises) and physical fitness tests inclusive of jump height,
73 sprint time and maximal aerobic capacity in talent identified junior rugby union players. Similarly,
74 Young, Grace, and Talpey (2014) noted moderate negative association between 20 m sprint time and
75 subsequent sprint technique and lower body power in junior AF; concluding that sprint time may be
76 mediated, in part, by the proficiency of fundamental athletic movement. However, the latter study
77 only investigated one physical fitness test in junior AF (20 m sprint), which while important, is not
78 comprehensive of the physical requisites of game-play (Gray & Jenkins, 2010). Nonetheless, these
79 identified associations suggest that the continued development of athletic movement skills may
80 influence the magnitude of training-related improvement of certain physical fitness outcomes.

81 Here, we propose that fundamental athletic movement assessments may therefore provide talent
82 recruiters with an indication of developmental potential with regards to performance on certain
83 physical fitness tests. For instance, a junior who produces a relatively superior physical fitness
84 outcome (i.e., jump height or sprint time) with less than proficient fundamental athletic movement
85 skill may hold greater potential for physical development when compared to a junior who produces
86 the same physical fitness outcome but with relatively superior fundamental athletic movement skill.
87 To date, research is yet to investigate the associations between fundamental athletic movement
88 (i.e., the process) and a range of physical fitness tests (i.e., the outcomes) in junior AF.

89 This study aimed to investigate the associations between fundamental athletic movement and
90 physical fitness tests in junior AF. Based upon previous research (Parsonage et al., 2014; Young et al.,
91 2014), it was hypothesised that a relatively superior physical fitness performance would be
92 associated with superior fundamental athletic movement skill.

93 **2. Methods**

94 A quantitative cross-sectional observational research design was used to test the study hypothesis.
95 From a total sample of 50 talent identified under 18 (U18) AF players, 44 (age range = 17.1 – 18.1 y;
96 186.7 ± 7.7 cm; 78.8 ± 9.2 kg) participated in the current study. All participants had been involved in
97 the same State Academy program for a minimum of two years. To be eligible for study inclusion, all
98 participants were to be injury free (no pain) and participating in regular training sessions for a
99 minimum of four consecutive weeks at the time of data collection. Participants were provided with a
100 full description of the testing procedures, and institutional ethical approval was obtained from the
101 relevant Human Ethics Advisory Committee, with all participants and parents (or guardians)
102 providing informed consent.

103 Each participant's fundamental athletic movement was assessed on one occasion at the conclusion
104 of the preseason phase of training in an attempt to standardise the assessment conditions. The
105 athletic movements assessed were the same as those reported by Woods, McKeown, Haff and
106 Robertson (2016) and consisted of an overhead squat, double lunge (performed on both left and
107 right legs), single leg Romanian deadlift (performed on both left and right legs), and a push up. This
108 represented a minor modification to the initial AAA proposed by McKeown, Taylor-McKeown,
109 Woods and Ball (2014) with these being chosen as they reflect the common fundamental athletic
110 movements required to perform specific conditioning exercises in team ball sports (Parsonage et al.,
111 2014). The overhead squat, double lunge and Romanian deadlifts were each performed with a light
112 weight wooden dowel to assist with the participants anatomical positioning during the production of
113 these movements. Operational definitions of each movement and their corresponding scoring

114 criteria are described in Table I. Each movement was scored across three assessment regions using a
115 three point scale, with each score anchored to a verbal descriptor. Scoring was conducted
116 retrospectively, with each movement being video recorded using a standard two-dimensional
117 camera (Sony, HDR-XR260VE) placed in the optimal position for assessment (sagittal and frontal).

118 ******INSERT TABLE I ABOUT HERE******

119 Each movement was performed for a total of five repetitions, with the exception of the push up,
120 which had a specific repetition target embedded within the scoring criteria (Table I). The difference
121 in repetition count between the push up and the other movements enabled the assessment of trunk
122 and hip control in muscularly fatiguing contexts (McKeown et al., 2014). Total score for each
123 movement (maximum of nine) was used as the independent criterion variable for analysis. All
124 participants were unfamiliar with this assessment protocol and were provided with specific cues
125 when required; inclusive of a verbal description of the scoring criteria. However, no feedback was
126 provided while the participants were performing the movements in an attempt to limit a potential
127 scoring bias (Frost, Beach, Callaghan, & McGill, 2013).

128 Using the video footage, two scorers independently assessed the participants' fundamental athletic
129 movement. Both scorers possessed more than four years' experience assessing athletic movement.
130 The inter-tester properties of the scoring criteria were assessed in order to establish reliability
131 specific to the target population in this study. Scores given across the three assessment criteria for
132 each movement by the primary scorer were compared to those provided by the secondary scorer.
133 Given the categorical nature of the data, the level of agreement between the two scorers was
134 measured using the weighted kappa statistic (κ), with the level of agreement being as follows: <0
135 less than chance agreement, 0.01-0.20 slight agreement, 0.21-0.40 fair agreement, 0.41-0.60
136 moderate agreement, 0.61-0.80 substantial agreement and 0.81-0.99 almost perfect agreement
137 (Landis & Koch, 1977).

138 Following the fundamental athletic movement assessment, all participants performed a battery of
139 five physical fitness tests. This consisted of a 20 m sprint test, the AFL agility test, a stationary
140 vertical jump test, a dynamic vertical jump test (performed using both left and right leg take-off),
141 and a 20 m multistage fitness test. These physical fitness tests were explicitly chosen in accordance
142 with recommendations provided in the talent identification literature (Keogh, 1999; Woods et al.,
143 2015) and representation of the common physical actions of AF game-play (Gray & Jenkins, 2010;
144 Pyne, Gardner, Sheehan, & Hopkins, 2005). Although the specific protocols and criterion variables
145 for each test are described in detail elsewhere (Woods et al., 2015), a brief procedural description of
146 the assessment conditions is provided. Most notably, each test was completed on wooden flooring
147 with the exception of the 20 m sprint and the AFL agility test, both of which were completed on a
148 synthetic running track. All testing was conducted in an indoor climate controlled laboratory, with
149 participants being asked to abstain from physical activity in the 24 hours prior to testing. The
150 physical fitness tests were performed in a circuit fashion and in the following order: 20 m sprint test;
151 AFL agility test; stationary vertical jump test; dynamic vertical jump test. Participants were randomly
152 divided into four groups and initially assigned to one of the four testing stations. The 20 m
153 multistage fitness test was undertaken after all other physical fitness testing had concluded, with
154 participants being split into two equal groups to complete this test.

155 *Statistical Analysis*

156 To test the study hypothesis, a Spearman's nonparametric correlation matrix was built in the *R*
157 statistical computing environment (version 3.2.2) (*R* Core Team, 2016). The scores obtained on each
158 athletic movement assessment were coded as the independent variables, while the scores obtained
159 on each physical fitness test were coded as the dependent variables. Using the *Hmisc* package
160 (Harrell, 2016), the 'cor()' argument was used to build a correlation coefficient matrix using the
161 "Spearman" method, while the 'rcorr()' argument was used to identify the level of significance of the
162 observed correlation coefficients within the matrix. The type-I error rate was set at $\alpha \leq 0.05$. The

163 strength of each correlation was as interpreted as follows: 0.00 – 0.20 negligible; 0.21-0.40 low;
164 0.41-0.60 moderate; 0.61-0.80 high; >0.81 very high (Mukak, 2012).

165 Additionally, a correlogram was built in the same statistical computing environment using the
166 *corrplot* package (Wei, 2013). Correlograms are useful schematics when visualising correlation
167 matrices that render the value of a correlation to depict its size and magnitude using colour mapping
168 of two hues in varying shading and lightness (Friendly, 2002). The intensity of the colour increases as
169 the correlation moves further away from zero. Here, the correlation coefficients were overlaid on
170 each symbol, with ‘red’ circular symbols being used to denote a negative coefficient, and ‘blue’
171 circular symbols used to denote a positive coefficient.

172 **3. Results**

173 Reliability analyses indicated that the strength of the inter-tester agreement for each assessment
174 criterion expressed moderate to substantial agreement between the two scorers ($\kappa = 0.61-0.80$). The
175 correlation matrix revealed a number of significant associations (Table II, Figure I). Specifically, score
176 on the overhead squat was positively associated with dynamic vertical jump height performed on
177 both left ($r_s = 0.40, P = 0.01$) and right ($r_s = 0.30, P = 0.05$) leg take-off, stationary vertical jump height
178 ($r_s = 0.32, P = 0.03$), and negatively associated with sprint time ($r_s = -0.35, P = 0.01$). The double lunge
179 performed on both left and right legs was positively associated with the level attained on the 20 m
180 multistage fitness test ($r_s = 0.37, P = 0.01$; $r_s = 0.30, P = 0.03$, respectively), dynamic vertical jump left
181 leg take off ($r_s = 0.42, P = 0.01$; $r_s = 0.38, P = 0.01$, respectively), stationary vertical jump height ($r_s =$
182 $0.44, P = 0.01$; $r_s = 0.40, P = 0.01$, respectively), and negatively associated with 20 m sprint time ($r_s = -$
183 $0.41, P = 0.01$; $r_s = -0.34, P = 0.03$, respectively). Finally, the score obtained when performing the
184 single leg Romanian deadlift on the left leg was positively associated with stationary vertical jump
185 height ($r_s = 0.33, P = 0.02$). Comparatively, no other fundamental athletic movements appeared to
186 significantly associate with performance on any of the physical fitness tests.

187 ******INSERT TABLE II ABOUT HERE******

188

****INSERT FIGURE I ABOUT HERE****

189 **4. Discussion**

190 The aim of this study was to investigate the associations between fundamental athletic movements
191 and physical fitness tests in junior AF. It was hypothesised that a relatively superior performance on
192 the physical fitness tests would meaningfully associate with fundamental athletic movement skill.
193 The results generally agreed with the study hypothesis, with five of the six physical fitness tests
194 being meaningfully associated with the production of the overhead squat, double lunge (both left
195 and right leg) and the single leg Romanian deadlift (left leg). These results yield translation for the
196 development of talented junior AF players. Specifically, the integration of a well-designed training
197 program enabling the development of the underlying athletic qualities associated with an overhead
198 squat and double lunge (namely trunk stability, single leg control, triple flexion, and shoulder
199 extension) may assist with the acquisition of physical outcomes of use for juniors during AF game-
200 play, such as accelerating, jumping and kicking. Further, the assessment of fundamental athletic
201 movement may provide both talent recruiters and strength and conditioning specialists in AF with a
202 deeper insight into a juniors developmental potential with regards to their physical fitness
203 performance. Thus, these results may be of assistance for talent identification practices when
204 explicitly measuring a player's physical development potential in AF at the U18 level.

205 The overhead squat is an athletic movement that requires hip mobility, trunk stability, thoracic
206 mobility, and shoulder integrity (Butler, Plisky, Southers, Scoma, & Kiesel, 2010; Kritiz, Cronon, &
207 Hume, 2009). Similar movement characteristics are required during sprinting and jumping actions
208 (Gamble, 2004), as well as tackling and marking actions (sport-specific movements commonly
209 performed during AF game-play). Our findings suggest that improvements in a junior AF players'
210 overhead squatting skill (presumably indicative of increased hip mobility, trunk stability, thoracic
211 mobility and shoulder integrity) may associate with an improved 20 m sprint time and dynamic and
212 stationary vertical jump height. This suggestion is supported by the results of Parsonage et al. (2014)

213 who indicated that bilateral squat competency was a predictor of countermovement jump height
214 and linear sprint time in talent identified U16 rugby union players. Further, Young et al. (2014)
215 reported that task-specific movement qualities and lower body power were associated with sprint
216 time in U18 AF players. Taken together, these findings indicate that training interventions oriented
217 around the acquisition of fundamental athletic movement skill variations may assist with the
218 development of certain physical fitness qualities in junior team sport athletes.

219 Similar to the overhead squat, the lunging motion is an integral movement pattern for a range of
220 sporting contexts given its influence on lower body joint loading during acceleration and
221 deceleration actions (Kuntze, Mansfield & Sellers, 2009). Jönhagen, Ackermann and Saartok (2009)
222 noted that the lunging motion was an important training modality for improving hamstring strength
223 and linear running speed in junior soccer players. The current study presents complementary results
224 to the work of Jönhagen et al. (2009) by demonstrating that the double lunging motion was
225 negatively associated with 20 m sprint time. Given this, it could be suggested that coaches of junior
226 team sport athletes may look to integrate lunging variations into their training and exercise
227 prescription, as its inclusion may augment the acquisition of an athletes linear running speed
228 capabilities; presumably beneficial for on-field success.

229 The implications of these findings for talent identification in junior AF are important to consider,
230 warranting interpretation. The association demonstrated here between certain fundamental athletic
231 movements and physical fitness tests suggests that athletic movement qualities may enhance a
232 junior's developmental potential. For example, a junior who performs the overhead squat with
233 relatively low skill but produces a relatively superior 20 m sprint time (due to mechanisms not
234 discussed here) may have a greater developmental potential when compared to a junior who
235 produces the same 20 m sprint time but performs the overhead squat with relatively high skill. The
236 former player description may be of greater value for talent recruiters, as our results suggest that
237 these players have the potential to improve their 20 m sprint time through the acquisition of

238 overhead squatting skill (amongst other qualities). As such, these players with relatively low
239 overhead squat skill may warrant being talent identified given the definition proposed by Vaeyens et
240 al. (2008).

241 Although associations were negligible for the single leg Romanian deadlift, it is important to
242 highlight the need to develop this fundamental athletic movement pattern in junior AF. Woods et al.
243 (2016) demonstrated a large developmental gap between elite junior and senior AF players with
244 regards to the fundamental athletic movements listed in this study. Most notably, the elite junior
245 players were reported as being more than 20% below their elite senior counterparts when
246 performing the single leg Romanian deadlift (Woods et al., 2016). This movement is often prescribed
247 to assist with muscular strength and motor control in the lumbar spine and posterior thigh (Brooks,
248 Fuller, Kemp, & Reddin, 2006), and is the fundamental progression when teaching more advanced
249 strength and power movements (Brooks et al., 2006). Further, AF players routinely hinge at the hip
250 under dynamic contexts to pick up ground-balls, a motion that would require pelvic and trunk
251 stability / mobility; fundamental athletic movement skills underpinning the production of the
252 Romanian deadlift. An inability to skilfully perform this movement may therefore hinder desired
253 training adaptations, which is problematic in AF given the considerable incidence of hamstring injury
254 within the AFL (Orchard, Seward, & Orchard, 2013). Thus, despite the inability of this isolated
255 athletic movement to meaningfully associate with the physical fitness qualities included in this
256 study, developing single leg Romanian deadlift technique may have important implications
257 elsewhere (i.e., for injury prevention) (Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010).

258 Although providing data that could be of use for the development and identification of talented
259 junior AF players, there are several factors that could be considered for future research. Most
260 notably, given the multi-dimensionality of AF game-play, physical fitness tests should only partially
261 inform talent identification (Woods et al., 2015). Future research should therefore consider the
262 relationship between technical skill outcomes (e.g. kicking proficiency) and fundamental athletic

263 movement in junior AF. Further, Lloyd, Oliver, Radnor et al. (2014) showed that physical
264 performance variation in youth soccer was influenced by both functional movement competence
265 and maturation. Thus, it would be of interest for future work to assess the relationship between
266 athletic movement competence as measured via the AAA and relative age and/or biological
267 maturation in junior AF. Lastly, to further validate the use of athletic movement assessments for the
268 identification of talented juniors, future work should look to implement a longitudinal research
269 design to ascertain the rate of change in a junior's athletic movement competence as they progress
270 through the talent pathway. The addition of work such as that described above may improve the
271 transferability and applicability of the current study by offering a deeper insight into the relationship
272 between performance qualities (e.g. the outcome) and fundamental athletic movement (e.g. the
273 process) in junior AF. Concomitantly, it may enable a greater understanding of how factors such as a
274 player's relative age and maturation contribute to the acquisition of athletic movement
275 competence.

276 **5. Conclusion**

277 Results demonstrated that certain fundamental athletic movements, namely the overhead squat
278 movement and double lunge (both left and right leg), were meaningfully associated with physical
279 fitness tests in junior AF players. This suggests that improvements in physical fitness qualities may
280 occur through concurrent increases in fundamental athletic movement skill. Developmental coaches
281 working with junior AF players may consider integrating training interventions that target the
282 acquisition of the fundamental athletic movement qualities underpinning the overhead squat and
283 double lunge actions. The acquisition of which may augment physical fitness adaptations,
284 subsequently assisting with on-field physical performance.

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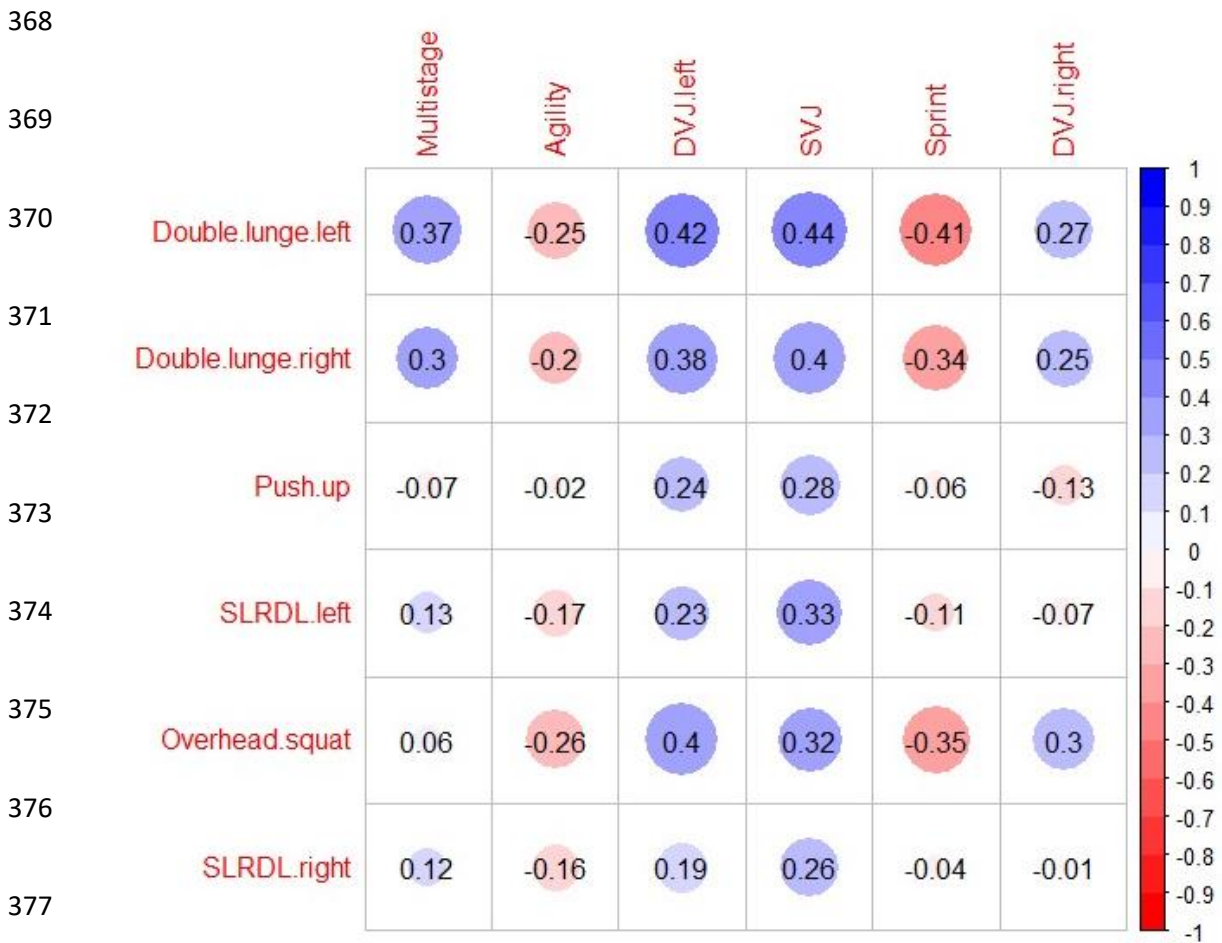
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366 **Figure 1.** Circularly rendered correlogram illustrating the correlation coefficients between each
 367 fundamental athletic movement and physical fitness test



378 *Note:* "SVJ" denotes stationary vertical jump, "DVJ" denotes dynamic vertical jump, "SLRDL" denotes
 379 single leg Romanian deadlift.

Table I. The AAA used to assess athletic movement competency as adapted from McKeown et al. (2014) and Woods et al. (2016)

Movement	Assessment Points	3	2	1
OH SQT	Upper Quadrant	Perfect hands above head/feet	Hands above head/feet	Unable to achieve position
	Triple Flexion	Perfect SQT to parallel	SQT to parallel (compensatory)	Unable to achieve position
	Hip Control	Neutral spine throughout	Loss of control at end of range	Excessive deviation
DL	Hip, Knee, Ankle	Alignment during movement	Slight deviation	Poor alignment
	Hip Control	Neutral hip position	Slight deviation	Excessive flex/ext
	Take off Control	Control	Jerking	Excessive deviation
Push Up	TB control	Perfect control/alignment	Perfect control/alignment for some	Poor body control for all reps
	Upper Quadrant	Perfect form/symmetry	Inconsistent	Poor scap. positioning for every rep
	x30 reps	Hits target count	-	< x 30
SL RDL	Hip Control – Frontal	Maintain neutral spine	Slight flex/ext through hips	Excessive flex/ext on SL stance
	Hip Control – Sagittal	No rotation	Slight rotation at end of range	Excessive rotation
	Hinge range	Achieves parallel	Can dissociate but not reach parallel	Cannot dissociate hips from trunk

Note: OH SQT, overhead squat; DL, double lunge; SL RDL, single leg Romanian deadlift; scap, scapula; flex, flexion; ext, extension

Table II. Correlation matrix denoting the ‘P values’ for each coefficient illustrated in the correlogram

	20 m sprint	Multi-stage	Agility	DVJ L	DVJ R	SVJ
Overhead squat	0.01	0.72	0.09	0.01	0.05	0.03
Double lunge (L)	0.01	0.01	0.10	0.01	0.07	0.01
Double lunge (R)	0.03	0.04	0.18	0.01	0.09	0.01
Push up	0.69	0.67	0.87	0.11	0.41	0.07
SL RDL (L)	0.77	0.45	0.29	0.22	0.92	0.02
SL RDL (R)	0.47	0.41	0.27	0.13	0.64	0.08

Note: “L” denotes Left, “R” denotes Right, “SL RDL” denotes Single leg Romanian deadlift, “DVJ” denotes dynamic vertical jump, “SVJ” denotes stationary vertical jump