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Running Title: Movement skill and physical fitness testing

Abstract

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

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

1. Introduction

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

According to Vaeyens et al. (2008), talent identification can be defined as the recognition of superior performance potential within a relatively homogenous athletic population. Despite this, common methods proposed to be of assistance for talent identification in AF appears to only identify superior current performance, which may not be indicative of long-term potential. Specifically, the use of traditional physical outcome-oriented (e.g. speed or distance) fitness tests predominate the talent identification literature in junior AF (Keogh, 1999; Woods, Raynor, Bruce, McDonald, & Collier, 2015). In part, this may be due to the physical requirements of AF game-play. For example, players' at all developmental levels are required to combine intermittent anaerobic running efforts with prolonged aerobic exercise during game-play (Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010). Measuring these physical fitness qualities would therefore appear warranted. However, although the use of such physical fitness tests may enable the identification of relatively superior physical performers, their discrete nature may be more depictive of an acute performance 'snapshot' rather than developmental potential (Vaeyens et al., 2008). Given their limited long-term predictive capability, their isolated administration may result in talent misclassification (MacNamara & Collins, 2011), where players are overlooked given an inability to perform a physical fitness test at a high standard at that current point in time. Thus, identifying certain attributes that may underpin the development of physical fitness qualities may be of value to both talent recruiters and strength and conditioning specialists, providing them with an indication of a juniors developmental potential.

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

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

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

2. Methods

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

Each participant's fundamental athletic movement was assessed on one occasion at the conclusion of the preseason phase of training in an attempt to standardise the assessment conditions. The athletic movements assessed were the same as those reported by Woods, McKeown, Haff and Robertson (2016) and consisted of an overhead squat, double lunge (performed on both left and right legs), single leg Romanian deadlift (performed on both left and right legs), and a push up. This represented a minor modification to the initial AAA proposed by McKeown, Taylor-McKeown, Woods and Ball (2014) with these being chosen as they reflect the common fundamental athletic movements required to perform specific conditioning exercises in team ball sports (Parsonage et al., 2014). The overhead squat, double lunge and Romanian deadlifts were each performed with a light weight wooden dowel to assist with the participants anatomical positioning during the production of these movements. Operational definitions of each movement and their corresponding scoring criteria are described in Table I. Each movement was scored across three assessment regions using a three point scale, with each score anchored to a verbal descriptor. Scoring was conducted retrospectively, with each movement being video recorded using a standard two-dimensional camera (Sony, HDR-XR260VE) placed in the optimal position for assessment (sagittal and frontal).

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

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

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

Statistical Analysis

To test the study hypothesis, a Spearman's nonparametric correlation matrix was built in the *R* statistical computing environment (version 3.2.2) (*R* Core Team, 2016). The scores obtained on each athletic movement assessment were coded as the independent variables, while the scores obtained on each physical fitness test were coded as the dependent variables. Using the *Hmisc* package (Harrell, 2016), the 'cor()' argument was used to build a correlation coefficient matrix using the "Spearman" method, while the 'rcorr()' argument was used to identify the level of significance of the observed correlation coefficients within the matrix. The type-I error rate was set at $\alpha \leq 0.05$. The strength of each correlation was as interpreted as follows: 0.00 – 0.20 negligible; 0.21-0.40 low; 0.41-0.60 moderate; 0.61-0.80 high; >0.81 very high (Mukak, 2012).

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

3. Results

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

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

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

4. Discussion

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

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

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

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

The implications of these findings for talent identification in junior AF are important to consider, warranting interpretation. The association demonstrated here between certain fundamental athletic movements and physical fitness tests suggests that athletic movement qualities may enhance a junior's developmental potential. For example, a junior who performs the overhead squat with relatively low skill but produces a relatively superior 20 m sprint time (due to mechanisms not discussed here) may have a greater developmental potential when compared to a junior who produces the same 20 m sprint time but performs the overhead squat with relatively high skill. The former player description may be of greater value for talent recruiters, as our results suggest that these players have the potential to improve their 20 m sprint time through the acquisition of overhead squatting skill (amongst other qualities). As such, these players with relatively low overhead squat skill may warrant being talent identified given the definition proposed by Vaeyens et al. (2008).

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

Although providing data that could be of use for the development and identification of talented junior AF players, there are several factors that could be considered for future research. Most notably, given the multi-dimensionality of AF game-play, physical fitness tests should only partially inform talent identification (Woods et al., 2015). Future research should therefore consider the relationship between technical skill outcomes (e.g. kicking proficiency) and fundamental athletic movement in junior AF. Further, Lloyd, Oliver, Radnor et al. (2014) showed that physical performance variation in youth soccer was influenced by both functional movement competence and maturation. Thus, it would be of interest for future work to assess the relationship between athletic movement competence as measured via the AAA and relative age and/or biological maturation in junior AF. Lastly, to further validate the use of athletic movement assessments for the identification of talented juniors, future work should look to implement a longitudinal research design to ascertain the rate of change in a junior's athletic movement competence as they progress through the talent pathway. The addition of work such as that described above may improve the transferability and applicability of the current study by offering a deeper insight into the relationship between performance qualities (e.g. the outcome) and fundamental athletic movement (e.g. the process) in junior AF. Concomitantly, it may enable a greater understanding of how factors such as a player's relative age and maturation contribute to the acquisition of athletic movement competence.

5. Conclusion

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

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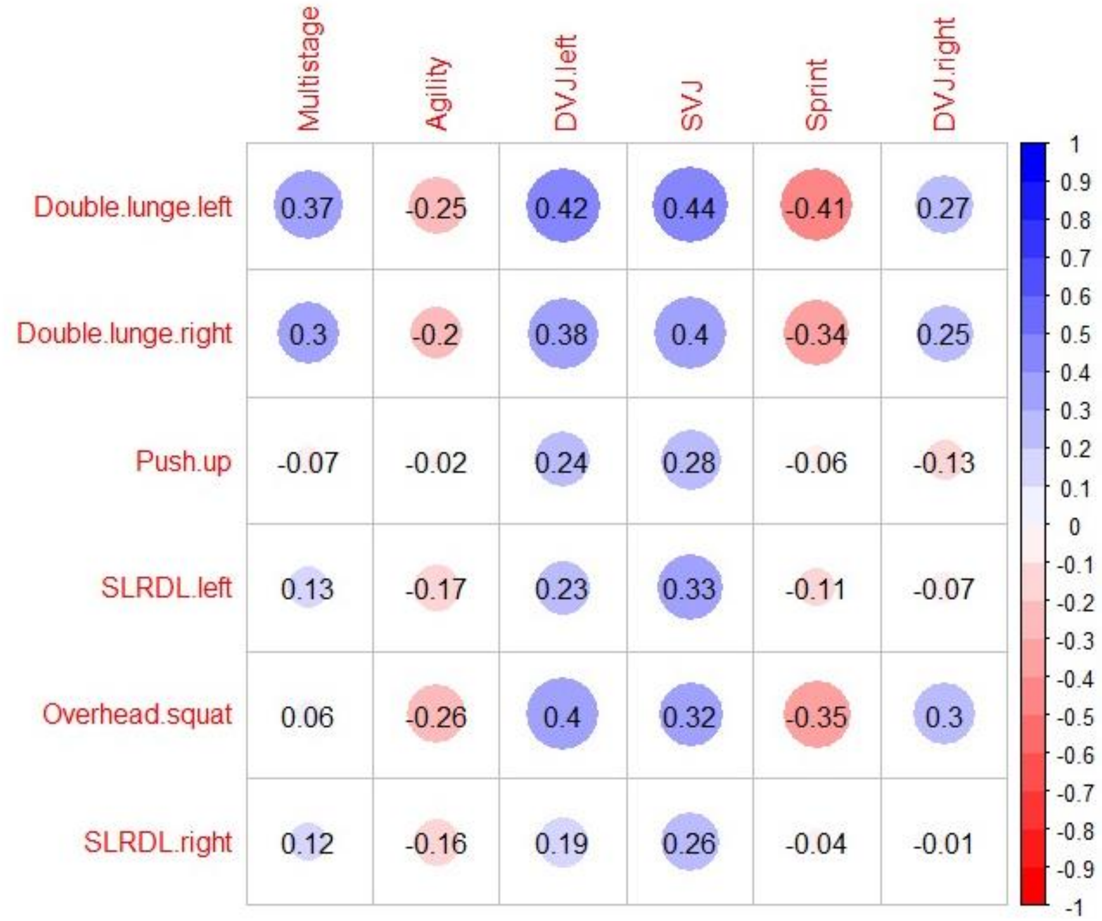
Figure 1. Circularly rendered correlogram illustrating the correlation coefficients between each fundamental athletic movement and physical fitness test



Note: "SVJ" denotes stationary vertical jump, "DVJ" denotes dynamic vertical jump, "SLRDL" denotes 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