Gaudion, Sarah L., Doma, Kenji, Sinclair, Wade, Banyard, Harry B., and Woods, Carl T. (2017) *Identifying the physical fitness, anthropometric and athletic movement qualities discriminant of developmental level in elite junior Australian football: implications for the development of talent.* Journal of Strength and Conditioning Research, 31 (7). pp. 1830-1839.

http://dx.doi.org/10.1519/JSC.0000000000001682

Journal of Strength and Conditioning Research Publish Ahead of Print
DOI: 10.1519/JSC.0000000000001682

Identifying the physical fitness, anthropometric and athletic movement qualities discriminant of developmental level in elite junior Australian football: Implications for the development of talent

Gaudion L. Sarah[a], Doma Kenji[a], Sinclair Wade[a], Banyard G. Harry[b,c], Woods T. Carl[a]*

[a]*Discipline of Sport and Exercise Science, James Cook University, Queensland, Australia*

[b]*Centre for Exercise and Sports Science Research (CESSR), School of Medical and Health Science, Edith Cowan University, Perth, Australia*

[c]*West Australian Football Commission, Perth, Australia*

*Corresponding Author

Carl Woods, Discipline of Sport and Exercise Science, James Cook University, Townsville, Queensland, Australia.

Ph: +61 08 4781 6550 Mob: +61 421254329 Email: carl.woods@jcu.edu.au

Running Title: Physical performance differences between developmental level in AF

ABSTRACT

This study aimed to identify the physical fitness, anthropometric and athletic movement qualities discriminant of developmental level in elite junior Australian football (AF). From a total of 77 players, two groups were defined according to their developmental level; under 16 (U16) (n = 40, 15.6 to 15.9 *y*), and U18 (n = 37, 17.1 to 17.9 *y*). Players performed a test battery consisting of seven physical fitness assessments, two anthropometric measurements, and a fundamental athletic movement assessment. A multivariate analysis of variance tested the main effect of developmental level (two levels: U16, U18) on the assessment criterions, whilst binary logistic regression models and receiver operating characteristic (ROC) curves were built to identify the qualities most discriminant of developmental level. A significant effect of developmental level was evident on nine of the assessments (d = 0.27 – 0.88; P <0.05). However, it was a combination of body mass, dynamic vertical jump height (non-dominant leg), repeat sprint time and score on the 20 m multistage fitness test that provided the greatest association with developmental level (AICc = 80.84). The ROC curve was maximised with a combined score of 180.7, successfully discriminating 89% and 60% of the U18 and U16 players, respectively (area under the curve = 79.3%). These results indicate that there are distinctive physical fitness and anthropometric qualities discriminant of developmental level within the junior AF talent pathway. Coaches should consider these differences when designing training interventions at the U16 level to assist with the development of prospective U18 AF players.

Key words: Talent development; talent identification; movement competence; long-term athlete development

INTRODUCTION

Given the financial and temporal constraints associated with the acquisition of sporting expertise, strategies that streamline athlete skill learning may be of value to governing sporting bodies (1). As such, the identification of talented junior athletes who demonstrate considerable performance potential is becoming an increasingly prominent practice for national sporting bodies, federations, and clubs (21, 26). This talent identification process affords practitioners with the opportunity to tailor training strategies to a select few juniors; referred to as talent development (TDE; defined as the process of exposing talent identified juniors to a learning environment that intends to expedite the acquisition of expertise) (29). Many national sporting organisations around the world have established elite TDE academies, with examples including ASPIRE in Qatar, and the United Kingdom High Performance Talent Program. Following suit, the Australian Football League (AFL) annually invests substantial resources into the identification and development of talented junior Australian football (AF) players believed to possess the qualities enabling their effective participation within the AFL (5).

These elite TDE programs in junior AF, referred to as State Academies, consist of two critical transition stages; the first occurs at under 16 years (U16) level, and the second occurs at the under 18 (U18) level. Thus, the elite junior talent pathway initiates at the U16 level in AF. The primary goal of these academies is to minimise performance discrepancies between elite junior and senior competition levels by exposing talent identified juniors to an opportunistic learning environment through the provision of superior coaching, player welfare, and sport science services (32). Consequently, it is understood that the current training interventions employed within these academies are based upon perceived performance differences between the junior and senior levels.

To date, research in AF has primarily focused on the identification of the performance differences between the elite U18 level and the AFL (elite senior level). Whilst these studies have demonstrated that measures of anthropometry (28), game-speed (5), athletic movement skill (30), and physical fitness characteristics (2) are discriminative of the elite junior (U18) to senior (AFL) level, no studies have investigated performance differences within the junior talent pathway. Specifically, there is yet to be work that identifies performance differences between the U16 and U18 level within a State Academy. This is an important gap to address, as identifying the performance qualities most discriminative of junior developmental level may create a strong basis for the establishment of targeted training interventions at the initial stage of the AF talent pathway (e.g. the U16 level), which may ultimately assist with the junior to senior developmental transition.

The benefit of identifying performance differences between juniors at different stages of a talent pathway has been shown in other team invasions sports, namely rugby league (24) and soccer (27). Vaeyens et al. (27) demonstrated that measures of running speed and technical skill were more discriminant of talent in soccer at the U13 and U14 level, while measures of cardiorespiratory endurance were more discriminant of talent at the U15 and U16 level. From these results, it was suggested that practitioners develop tailored training interventions for each developmental level with the aim of minimising the performance gaps between these junior levels (27).

Across each developmental level in AF, players require a unique combination of physical (e.g. repeat sprint ability and maximal aerobic capacity), technical (e.g. kicking and handballing), and perceptual (e.g. offensive and defensive decision-making) skills to enable a succesful performance (12, 31, 32). Given this, recent talent identification models in AF have progressed toward the use of multidimensional designs to assist with the recognition of superior holistic performance qualities (32). Similar multidiemsnional work is required to assist with the development of talent identified juniors within the AF talent pathway. To progress toward this multidimensionality in talent development, work is required to examine developmental differences (e.g. U16 and U18) with regards to each component required for a succesful performance (e.g. physical, technical and perceptual). Acknowledging this, the aim of this study was to provide an initial basis for the development of a multidimensional model of TDE in AF by identifying the physical fitness, anthropometric and athletic movement qualities discriminant of developmental level in the elite junior talent pathway. Given their longitudinal exposure to an opportunistic learning environment, it was hypothesised that the U18 players would possess superior performance qualities relative to their U16 counterparts. The subsequent findings of this work are likely to assist with the design of targeted training interventions purported to assist with TDE in junior AF, which may ultimately enhance the overall elite junior to senior transition for talent identified juniors.

METHODS

Experimental Approach to the Problem

To test the study hypothesis, an observational cross sectional research design was used. All players participating in this study performed a test battery that consisted of physical fitness, anthropometric and athletic movement skill assessments. The construction of this test battery was based on recommendations provided in the literature (10, 20, 30, 31, 35). Testing took place at the end of the player’s respective preseason phase of training in an attempt to standardise testing conditions.

Subjects

Data was collected from a total sample of 77 talent identified junior AF players who all originated from the same State Academy. From this total sample, two player groups were defined based upon their developmental level; U16 (n = 40, 15.6 to 15.9 *y*) and U18 (n = 37, 17.1 to 17.9 *y*). All of the players selected into the State Academy participated in the study. Ethical approval was granted by the relevant Human Research Ethics Committee prior to data collection and parental consent was obtained for players.

Procedures

Players completed the following test battery at an indoor location in one testing session on the same day; standing height, body mass, 20 m sprint test, the AFL agility test, repeat sprint test, a stationary vertical jump (SVJ) test, a dynamic vertical jump (DVJ) test (performed on both dominant (D) and non-dominant (ND) foot take-off), the 20 m multistage fitness test, and an athletic movement skill assessment (16). All players completed a standardised warm up prior to the physical fitness tests, which consisted of light jogging, unilateral and bilateral countermovement jumps and dynamic stretches, taking approximately 15 minutes to complete. The anthropometric measurements of standing height and body mass were the first measurements obtained. Players were required to remove their footwear prior to commencing the anthropometric assessments and measurements were recorded to the nearest 0.1 cm and 0.1 kg, respectively.

The physical fitness assessments were completed in a circuit fashion with the players being randomly allocated to a starting point in smaller groups consisting of six to eight players. The following order was applied to the circuit: 1) 20 m sprint test; 2) AFL agility test; 3) SVJ test; 4) DVJ dominant foot (DVJD) test; 5) DVJ non-dominant (DVJND) foot test; 6) repeat sprint test. For tests consisting of multiple trials, one minute was allocated between trials, and two minutes was allocated between the conclusion and initiation of each testing station. Verbal encouragement was provided for each physical test requiring maximal effort. Following the physical fitness tests, players performed the athletic movement skill assessment. This assessment consisted of six movements: 1) overhead squat; 2) single leg Romanian deadlift right leg; 3) single leg Romanian deadlift left leg; 4) double lunge right leg; 5) double lunge left leg; and 6) push up. Finally, all players undertook the 20 m multistage fitness test following the completion of all other testing; being split into approximately two equal-sized groups within their respective developmental level to perform this test. Although the measurement protocols for assessment are provided in greater detail elsewhere (30, 31), a brief procedural description is provided below.

Stationary and dynamic vertical jump height: Jump heights were obtained using a Vertec jump device (Swift Performance Equipment, Lismore, Australia). SVJ height was recorded via a stationary bilateral countermovement jump, while the DVJ was performed off the players outside foot following a five metre straight line run-up. This was completed for both dominant and non-dominant foot take-off, with foot dominance being defined as the players preferred kicking foot. At the highest point of each jump, players were instructed to displace the vanes of the Vertec, with the highest vane displaced by the inside hand being recorded. Final jump height was recorded (stationary and dynamic) as the difference between standing height (obtained prior to completing both jumps) and the highest vane displaced whilst jumping. Three trials were completed for each jump (stationary/dynamic) with the maximum jump height obtained being used as the criterion value for analysis.

20 m sprint: Timing lights (Swift Performance Equipment, Lismore, Australia) were used to measure each player's 20 m sprint time, with gates being placed at the start line, and 20 m distance, 1.5 m wide. Players commenced the sprint when they were ready in a stationary upright-position, with their lead foot on the start line, eliminating reaction time. Times were recorded to the nearest 0.01 s, the fastest 20 m time of three trials was used as the criterion values for analysis.

AFL agility test: The same agility test as described by Young and Pryor (35) was used. As shown in Figure 1, this test required the players to manoeuvre as fast as possible around five 1.1 m high poles, each with a circumference of 12 cm. If a pole was displaced during the test, the trial was abandoned and re-started after 1 minute. Players were not allowed to touch the ground with their hand when changing direction, with the trial being abandoned if this occurred. Timing lights were placed 1.5 m wide, and were positioned at the start and finish of the test. The fastest of the three trials was used as the criterion value for analysis, with times being recorded to the nearest 0.01 s.

******INSERT FIGURE 1 ABOUT HERE******

Repeat sprint test: Repeated sprint ability was assessed via the use of six, 30 m repeated sprints at maximal effort, leaving on a 20 s cycle (20). Timing lights were placed at the start and finish lines, 1.5 m wide with players sprinting in both directions (three sprints in each direction). A stationary start-line was positioned 0.5 m behind each set of timing lights and players were given 10 m (marked with a cone) to decelerate after each sprint. Players then walked back to the start position to prepare for the next sprint. Timing signals, including a 10 s and 5 s warning and the starting beep, were emitted from a pre-recorded MP3 audio broadcast. Times were recorded to the nearest 0.01 s, and the cumulative time of all six repeated sprints was used as the criterion variable for analysis.

Maximal aerobic capacity: The 20 m multistage fitness test was used to estimate player's maximal aerobic capacity (10). Players were required to continually run back and forth along a 20 m distance, keeping in time with a monotonic 'beep' emitted by a compact disk. The time between each beep (shuttle) gradually decreased as the test (or levels) progressed; requiring players to incrementally increase their running speed. The test was concluded when the player either reached volitional exhaustion or was unable to keep time with the beeps on two consecutive occasions. The highest level and shuttle successfully obtained by each player was used as the criterion value for analysis.

Athletic movement skill assessment: The players performed the same athletic movement protocol as described by Woods et al. (30). This assessment included an overhead squat, double lunge and single leg Romanian deadlift (both movements performed on both left and right legs), and a push up. This athletic movement assessment has been discriminately validated for use in the comparison of athletic movement competence between elite junior and senior AF players (30). The overhead squat, double lunge and single leg Romanian deadlifts were all performed with a wooden dowel to assist with the anatomical positioning of the player's limbs when performing these movements. No feedback or verbal encouragement was provided to the players during the movement production in an attempt to limit a potential scoring bias effect (11). Each movement was scored across three assessment points using a three-point scale (maximum of nine points); with each point being anchored to a description of the movement characteristics (16, 30). Each movement was performed for a total of five repetitions, except for the push up, which had specific repetition targets embedded within the scoring criteria. The scoring criteria is presented in Table 1. Each movement was scored retrospectively by one researcher using video recorded footage acquired using a standard two-dimensional camera (Sony, HDR-XR260VE) placed in optimal positions for assessment (sagittal and frontal). The total scores for each movement (maximum of nine) were used as the criterion variables for analysis.

****** INSERT TABLE 1 ABOUT HERE ******

Statistical Analysis

To establish the measurement properties of the athletic movement skill scoring procedure, the intra-rater reliability was assessed. The entire U18 sample was scored on two separate occasions by the same researcher, separated by seven days. Given the categorical nature of the scoring process, the level of agreement between the two scoring occasions was assessed using the weighted kappa statistic (k), with the level of agreement defined 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 (15).

Descriptive statistics (mean ± standard deviation) were calculated for all physical fitness, anthropometric and athletic movement skill criterions. The effect size of developmental level (two levels: U16, U18) on each test criterion was calculated using Cohen's *d* statistic; where an effect size of *d* = 0. 10 – 0.20 was considered small, *d* = 0.21 – 0.50 moderate, *d* = 0.51 – 0.80 large and *d* >0.80 very large (8). Following this, a multivariate analysis of variance (MANOVA) was used to test the main effect of developmental level on the test criterions with the Type-I error rate set at $\alpha < 0.05$. All between group comparisons were conducted using SPSS (version 21, SPSS Inc., USA).

Following this, binary logistic regression models were built to identify the test criterions yielding the greatest association with the main effect of developmental level. Each test criterion that significantly differed according to the MANOVA were coded as the explanatory variables, and developmental level was coded as the binary response variable (1 = U18, 0 = U16). All modelling was performed using the computing environment *R* (Version 3.1.3 *R* Core Team, 2015). Model parsimony was found by reducing the full model using the 'dredge' function in the *MuMIn* package (6). This function returns the best model using Akaike's Information Criterion (AICc). Further, to ensure the strength of the model fit, a null model was built and used a comparator.

Finally, to assess the discriminative ability of the most parsimonious model and its single term predictors, the *pROC* package (22) was used to conduct a sensitivity versus specificity analysis. Receiver operating characteristic (ROC) curves were built, with the area under the curve (AUC) being calculated. An AUC of 1 (100%) represents perfect discriminative power for a binary response variable. For each model, the point on the curve that generated the highest AUC was considered the value at which a 'cut off' might be acceptable for discriminating the two developmental levels, and thus the 'benchmark' value for which coaches could base their training interventions designed to reduce potential developmental gaps.

RESULTS

The level of agreement between the two scoring sessions for the athletic movement skill assessment ranged from 'substantial' to 'almost perfect' for each movement. There was a significant effect of developmental level on the physical fitness, anthropometric and athletic movement skill criterions ($V = 0.498$, $F = 4.031$, $P < 0.05$). Specifically, there was a significant effect of developmental level on body mass, SVJ, DVJD, DVJND, 20 m sprint, agility, repeated sprints, 20 m multistage fitness test, and the push up movement (Table 2). On average, the U18 group performed each of these assessments with a higher level of proficiency than the U16 group (Table 2). Further, body mass, SVJ, DVJD, DVJND, agility and the push up movement demonstrated large to very large effect sizes (Table 2).

****** INSERT TABLE 2 ABOUT HERE ******

These nine test criterions were then included as explanatory variables within the full binary logistic regression model. However, of these, body mass, DVJND, repeated sprints, and the 20 m multistage fitness test were retained in the best reduced model (Table 3).

******INSERT TABLE 3 ABOUT HERE******

The ROC curve for this full model was maximised when the combined score of these four explanatory variables equalled 180.7 (AUC = 79.3%; Figure 2). Of the U18 players, 33 (89%) recorded a combined score of ≥180.7, while of the U16 players, 16 (40%) were deemed misclassified due to recording a combined score of ≥180.7. Thus, the full model detected 89% of the true positives (U18 players) and 60% of the true negatives (U16 players).

******INSERT FIGURE 2 ABOUT HERE******

From the explanatory variables included in the full model, DVJND height provided the greatest between group discrimination (AUC = 74.6%; Figure 3b). Of the 37 U18 players, 21 (57%) recorded a DVJND height of 71.5 cm or greater, while only 8 (20%) of the U16 players recorded a DVJND height of 71.5 cm or greater. Accordingly, a DVJND height of 71.5 cm detected 57% and 80% of the U18 and U16 players, respectively. The next best single term variable to provide developmental discrimination was repeat sprint time (AUC = 73.1%; Figure 3c), followed by body mass (AUC = 67.2%; Figure 3a), and finally the score obtained on the 20 m multistage fitness test (AUC = 65%; Figure 3d).

****INSERT FIGURE 3 ABOUT HERE****

DISCUSSION

This study aimed to identify the physical fitness, anthropometric and athletic movement qualities discriminant of developmental level in junior AF. Given their longitudinal exposure to an opportunistic learning environment, it was hypothesised that the U18 players would possess superior performance qualities relative to their U16 counterparts. The results partially supported this hypothesis, with it being the combination of body mass, DVJND height, repeat sprint time, and score on the 20 m multistage fitness test that provided the greatest association with developmental level. Specifically, a combined score of 180.7 successfully discriminated 89% and 60% of the U18 and U16 players, respectively. This finding is in general agreement with work that has shown the utility of these measures for identifying talent at the U18 level (13, 18, 31). Thus, AF coaches at the U16 level may consider implementing training interventions oriented around increasing their players lower body power, repeated sprint ability, and maximal aerobic capacity. This may not only improve the developmental transition to the U18 level, but may also increase a player's prospective likelihood of being talent identified at the U18 level. However, the development of players' movement competency may be a more immediate concern for coaches given the low scores obsereved at both developmental levels. It is imperative that coaches aim to increase athletic movement skill in junior AF players, as poorly developed movement competency may inhibit a player's ability to tolerate advanced training demands, limiting their potential to progress through the talent pathway (17).

Of note was that the most parsimonious full model did not retain measures of athletic movement skill. Consequently, despite the reported relationship between athletic movement competency and physical performance outcome assessments (17, 33), it appears that the U18 player's superior physical fitness qualities were not operationalised by a superior athletic movement competency in this study. Rather, both the U16 and U18 players in this study demonstrated a relatively low movement competency when compared to values obtained by senior AFL players (30). It could be concluded that the U18 player's superior physical fitness reflects a potentially prolonged exposure to targeted training interventions oriented around physical performance outcomes. Specifically, work has demonstrated a gap in the physical requirements of game-play between the U18 and AFL levels (5). Presumably, coaches at the U18 level are designing physical training interventions based on these differences, with the aim of improving the U18 to AFL transition.

It is important to acknowledge the potential maturation differences between developmental levels, which could account for the observed differences. Gastin et al. (12) demonstrated that biological maturation correlated with score on the 20 m multistage fitness test and 20 m sprint time in junior AF players age U11 to U19. However, the within age-grouping influences of biological maturation on running performance were more pronounced in players chronologically aged below 15 *y* (12). Consequently, given that the age of our players ranged from 15.6 to 17.9 *y*, it is unlikely that biological maturation was the primary mechanism underpinning the differences between the two developmental levels in this instance. Nonetheless, biologically mature juniors within the same age category may be at a performance advantage relative to those who have not yet reached biological maturity (12). Thus, future work should investigate the influence of biological maturation on the production of physical fitness and athletic movement qualities in the elite junior AF talent pathway.

Given the multi-dimensionality of AF game-play, temporal constraints often limit the amount of time allocated to the development of physical performance qualities. These results suggest that if coaches at the U16 level cannot explicitly allocate training time to the three physical fitness qualities included in the full regression model, they may wish to prioritise the development of a player's DVJ, given this criterion demonstrated the greatest single term developmental discrimination (Figure 3b). Interestingly, a secondary finding of this study was the discrepancy between the dominant and non-dominant foot jump heights; with it appearing less pronounced at the U18 level compared to the U16 level (Table 2). As the dynamic jumping action is multifactorial in nature, the asymmetry of the U16 players may indicate that the U18 players possess greater strength, power, and/or coordination in their lower body (14, 23, 25). Importantly, increases in maximal strength and power of the lower body are known to enhance performance tasks such as running and jumping (3, 9). Therefore, it may be beneficial for U16 players to engage in strength training interventions that incorporate bilateral and unilateral lower body exercises with the aims of enhancing performance and reducing any observed bilateral deficit between dominant and non-dominant limbs when progressing toward the U18 level. When translated to an on-field performance, a greater DVJ may contribute to success in aerial ball contests, with these players potentially being viewed advantageously by talent recruiters (31). However, the considerably poor performances noted at both developmental levels for the athletic movement assessment suggests that coaches in the AF talent pathway should look toward improving the athletic movement qualities of players prior to integtrating targeted strength training interventions. Further, improving the effeicincy of production with regards to athletic movement qualities, such as the overhead head, may innately augment the development of physical fitness qualities, such as jump height and/or sprint time (17).

Repeat sprint ability is a critical physical quality for players to possess in junior and senior AF competitions given the intermittent nature of game-play (5). However, the gap between elite junior and senior AF competitions with regards to the number of repeated efforts performed during game-play appears to be increasing (5). Notably, Burgess et al. (5) reported that AFL players generated greater maximum running velocities, and performed more repeated sprint efforts per minute of game-play relative to players in an elite U18 competition. The results of the current study emphasise the need for training interventions that develop high anaerobic capacities and repeated sprint efforts at the U16 level. Further, since the aim of a State Academy is to minimise performance discrepancies between elite junior and senior levels, there is a need to enhance the physical capacities of U18 and U16 players to allow them to compete at the elite senior level (4). It is speculated that the difference noted here with regards to repeat sprint ability is a product of training environment. For example, it is hypothesised that players at the U18 level partook in more physically focused anaerobic training drills relative to their U16 counterparts, as coaches at the U18 level aimed to prepare players for the rigours of elite senior competitions (i.e., the AFL). Given this speculation, it would be of interest for future work to investigate the developmental histories of players in the AF talent pathway. By doing so, it may assist with the explanation of the superior performance qualities obsereved by the U18 players in the current study.

The results from this study show that estimated maximal aerobic capacity varies significantly between developmental levels within the junior talent pathway. Despite not yet being elucidated within the literature, it could be suggested that the difference noted in score obtained for the 20 m multistage fitness test is reflective of the physical requirements of game-play at the U16 and U18 levels. Specifically, players at the U18 level may be more equipped to cover greater running distances during game-play given their superior maximal aerobic capacity (as estimated via the 20 m multistage fitness test). Developing this physical quality at the U16 level may afford players at this initial stage of development with an advantageous base for which to manage the potential increased aerobic requirements of U18 game-play.

Despite the high level of between group discrimination noted for the full regression model, of particular interest were the 16 misclassified U16 players. This indicates that these misclassified U16 players were potentially already physically equipped to participate in the U18 competition given their combination of physical performance qualities. Consequently, in addition to being used to drive developmental practices at the U16 level, the combination of these four assessments could be used as an initial identification of 'readiness' for U16 players to enter the U18 level. With that said, it is important to note that this study only investigated one element of effective game-play in AF (physicality). Whilst an advantageous level of physicality is required in AF, overall success in the game is underpinned by multidimensional performance qualities (physical, technical and perceptual) (32). Future work should progress the results presented here and work toward the identification of the multidimensional performance qualities discriminant of developmental level in the junior AF talent pathway.

In conclusion, this work demonstrates that talent identified U18 AF players possess superiorities in certain physical fitness and anthropometric qualities relative to their U16 counterparts. It was the combination of body mass, DVJND height, repeat sprint time, and score on the 20 m multistage fitness test that provided the greatest developmental discrimination. Given these findings, future work should look to identify the technical and/or perceptual qualities discriminant of developmental level in junior AF. This may operationalise the establishment of a multidiemsnional approach to TDE in elite junior AF.

PRACTICAL APPLICATIONS

There are three main practical applications to stem from this work. Firstly, coaches at the U16 level should look to design training interventions explicitly focused on the development of DVJ height, repeated sprint ability, and maximal aerobic capacity. This may assist with the U16 to U18 developmental transition, which may ultimately lead to a smoother U18 to AFL transition. To further this, coaches may wish to consider improving the athletic movement competency of their players, which may ultimately augment the development of desired physical fitness qualities. Secondly, given foreseeable temporal constraints limiting the focus on all three physical fitness qualities, coaches at the U16 level may wish to target the development of lower body power and coordination to assist with the development of dynamic jumping capability. Given the ROC curve analysis performed in this study, coaches could use a DVJND height of 71.5 cm as an appropriate developmental benchmark for U16 players looking to progress into the U18 level. Lastly, the binary logistic regression model built in this study may provide coaches with an initial means of which to identify U16 players capable of managing the physical requirements of game-play at the U18 level.

References

1. Abernethy, B. Introduction: developing expertise in sport – how can research inform practice. In: *Developing Sport Expertise: Researchers and Coaches Put Theory into Practice*. D. Farrow, J. Baker and C. MacMahon, eds. Abingdon: Routledge, 2008. pp. 1-14
2. Bilsborough, JC, Greenway, KG, Opar, DA, Livingstone, SG, Cordy, JT, Bird, SR, and Coutts, AJ. Comparison of anthropometry, upper-body strength, and lower-body power characteristics in different levels of Australian football players. *J Strength Cond Res* 29: 826-834, 2015.
3. Bloomquist, K, Langberg, H, Karlsen, S, Madsgaard, S, Boesen, M, and Raastad, T. Effect of range of motion in heavy load squatting on muscle and tendon adaptations. *Eur J Appl Physiol* 113: 2133-2142, 2013.

4. Burgess, D, Naughton, G, and Hopkins, W. Draft-camp predictors of subsequent career success in the Australian Football League. *J Sci Med Sport* 15: 561-567, 2012.

5. Burgess, D, Naughton, G, and Norton, K. Quantifying the gap between under 18 and senior AFL football: 2003-2009. *Int J Sports Physiol Perform* 7: 53-58, 2012.

6. Burnham, KP, and Anderson, DR. *Model selection and multimodel interface: A practical information-theoretic approach, 2nd ed.* New York: Springer-Verlag, 2002.

7. Buttifant, D. Physiological and performance characteristics of Australian Football League players. *J Sport Sci* 17: 808-809, 1999.

8. Cohen, J. *Behavioural Sciences.* New Jersey: Lawrence Erlbaum Associates Inc., 1988.

9. Comfort, P, Haigh, A, and Matthews, MJ. Are changes in maximal squat strength during preseason training reflected in changes in sprint performance in rugby league players? *J Strength Cond Res* 26: 772-776, 2012.

10. Ellis, L, Gastin, PB, Lawrence, S, Savage, B, Buckeridge, A, and Stapff, A. Protocols for the physiological assessment of team sport players. In: *Physiological Tests for Elite Athletes*. C. G. Gore, ed. Champaign, IL: Human Kinetics, 2000.

11. Frost, DM, Beach, TA, Callaghan, JP, and McGill, SM. FMS Scores Change With Performers' Knowledge of the Grading Criteria-Are General Whole-Body Movement Screens Capturing "Dysfunction"? *J Strength Cond Res* 29: 3037-3044, 2015.

12. Gastin, PB, Bennett, G, and Cook, J. Biological maturity influences running performance in junior Australian football. *J Sci Med Sport* 16: 140-145, 2013.

13. Keogh, J. The use of physical fitness scores and anthropometric data to predict selection in an elite under 18 Australian rules football team. *J Sci Med Sport* 2: 125-133, 1999.

14. Kollias, I, Hatzitaki, V, Papaiakovou, G, and Giatsis, G. Using principal components analysis to identify individual differences in vertical jump performance. *Res Q Exerc Sport* 72: 63-67, 2001.

15. Landis, JR and Koch, GG. The measurement of observer agreement for categorical data. *Biometrics* 33: 159-174, 1977.

16. McKeown, I, Taylor-McKeown, K, Woods, C, and Ball, N. Athletic ability assessment: a movement assessment protocol for athletes. *Int J Sports Phys Ther* 9: 862-873, 2014.

17. Parsonage, JR, Williams, RS, Rainer, P, McKeown, I, and Williams, MD. Assessment of conditioning-specific movement tasks and physical fitness measures in talent identified under 16-year-old rugby union players. *J Strength Cond Res* 28: 1497-1506, 2014.

18. Pyne, DB, Gardner, AS, Sheehan, K, and Hopkins, WG. Fitness testing and career progression in AFL football. *J Sci Med Sport* 8: 321-332, 2005.

19. Pyne, DB, Gardner, AS, Sheehan, K, and Hopkins, WG. Positional differences in fitness and anthropometric characteristics in Australian football. *J Sci Med Sport* 9: 143-150, 2006.

20. Pyne, DB, Saunders, PU, Montgomery, PG, Hewitt, AJ, and Sheehan, K. Relationships between repeated sprint testing, speed, and endurance. *J Strength Cond Res* 22: 1633-1637, 2008.

21. Regnier, G, Salmela, J, and Russell, SJ. *Talent detection and development in sport.* New York: Macmillan, 1993.

22. Robin, X, Turck, N, Hainard, A, Tiberti, N, Lisacek, F, Sanchez, JC, and Muller, M. pROC: an open-source package for R and S+ to analyze and compare ROC curves. *BMC Bioinformatics* 12: 77, 2011.

23. Stephens, TM, 2nd, Lawson BR, DeVoe DE, and Reiser RF, 2nd. Gender and bilateral differences in single-leg countermovement jump performance with comparison to a double-leg jump. *J Appl Biomech* 23: 190-202, 2007.

24. Till, K, Jones, B, Darrall-Jones, J, Emmonds, S, and Cooke, C. Longitudinal development of anthropometric and physical characteristics within academy rugby league players. *J Strength Cond Res* 29: 1713-1722, 2015.

25. Tomoika, M, Owings, TM, and Grabiner, MD. Lower extremity strength and coordination are independent contributors to maximum vertical jump height. *J Appl Biomech* 17: 181-187, 2001.

26. Vaeyens, R, Gullich, A, Warr, CR, and Philippaerts, R. Talent identification and promotion programmes of Olympic athletes. *J Sport Sci* 27: 1367-1380, 2009.

27. Vaeyens, R, Malina, RM, Janssens, M, Van Renterghem, B, Bourgois, J, Vrijens, J, and Philippaerts, RM. A multidisciplinary selection model for youth soccer: the Ghent Youth Soccer Project. *Br J Sports Med* 40: 928-934, 2006.

28. Veale, JP, Pearce, AJ, Buttifant, D, and Carlson, JS. Anthropometric profiling of elite junior and senior Australian football players. *Int J Sports Physiol Perform* 5: 509-520, 2010.

29. Williams, AM, and Reilly, T. Talent identification and development in soccer. *J Sport Sci* 18: 657-667, 2000.

30. Woods, CT, McKeown, I, Haff, GG, and Robertson, S. Comparison of athletic movement between elite junior and senior Australian football players. *J Sport Sci* 34: 1260-1265, 2016.

31. Woods, CT, Raynor, AJ, Bruce, L, McDonald, Z, and Collier, N. Predicting playing status in junior Australian Football using physical and anthropometric parameters. *J Sci Med Sport* 18: 225-229, 2015.

32. Woods, CT, Raynor, AJ, Bruce, L, McDonald, Z, and Robertson, S. The application of a multi-dimensional assessment approach to talent identification in Australian football. *J Sport Sci* 34: 1340-1345, 2016.

33. Young, WB, Grace, S, and Talpey, S. Association between leg power and sprinting technique with 20-m sprint performance in elite junior Australian football players. *Int J Sports Sci Coach* 9: 1153-1160, 2014.

34. Young, WB, and Pryor, L. Relationship between pre-season anthropometric and fitness measures and indicators of playing performance in elite junior Australian Rules football. *J Sci* Med Sport 10: 110-118, 2007.

Figure 1. The AFL agility test as described by Young and Pryor (34)

Figure 2. The ROC curve for the full binary logistic regression model indicating the point at which the greatest developmental discrimination occurred

Figure 3. The ROC curves for body mass (a), DVJND height (b), repeat sprint time (c), and the 20 m multistage fitness test (d)

Table 1. The fundamental athletic movement competency assessment as adapted from McKeown et al. (16) and Woods et al. (30)

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 (L/R)	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 (L/R)	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; L left; R Right

Table 2. Between group effects for each physical fitness, anthropometric and athletic movement skill assessment

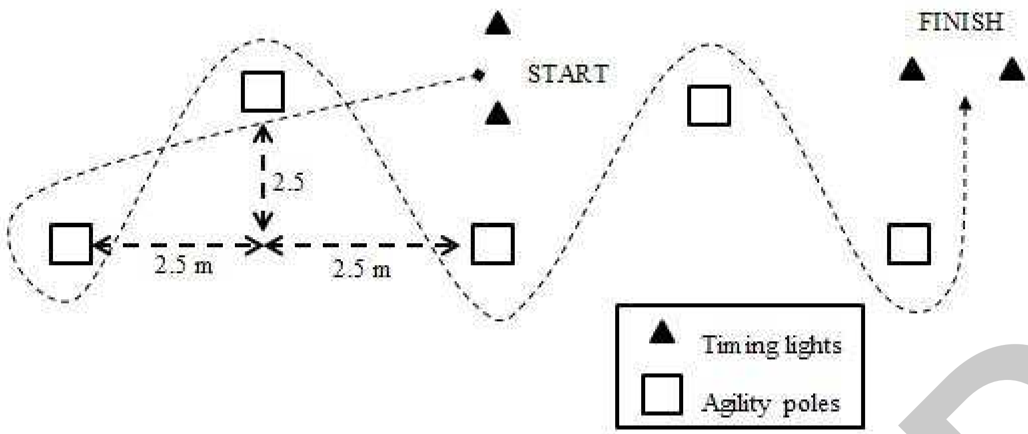
Measurement	**U18**	**U16**	***d***
Standing height (cm)	183 ± 7.2	181.3 ± 6.9	0.24
Body mass (kg)*	78.1 ± 8.5	72.6 ± 8.5	0.62
Standing vertical jump (cm)*	62.8 ± 7.9	57.4 ± 8.3	0.64
Dynamic vertical jump (L) (cm)*	75.2 ± 7.7	71.4 ± 5.7	0.55
Dynamic vertical jump (R) (cm)*	73.2 ± 8.5	65.9 ± 6.4	0.88
20m sprint (s)*	3.06 ± 0.09	3.11 ± 0.12	0.47
Agility (s)*	8.45 ± 0.25	8.58 ± 0.28	0.77
Repeated sprints (s)*	26.89 ± 0.98	27.64 ± 0.81	0.48
20m multistage fitness test (level.shuttle)*	13.2 ± 1.0	12.6 ± 1.2	0.27
Overhead squat	5.1 ± 1.2	5.4 ± 1.1	0.27
Single leg Romanian deadlift (R)	4.2 ± 1.4	3.8 ± 1.1	0.34
Single leg Romanian deadlift (L)	4.1 ± 1.4	3.8 ± 1.3	0.24
Double lunge (R)	5.7 ± 0.9	5.7 ± 0.9	0.08
Double lunge (L)	5.8 ± 1.0	5.6 ± 1.0	0.16
Push up*	5.5 ± 1.1	4.9 ± 1.2	0.52

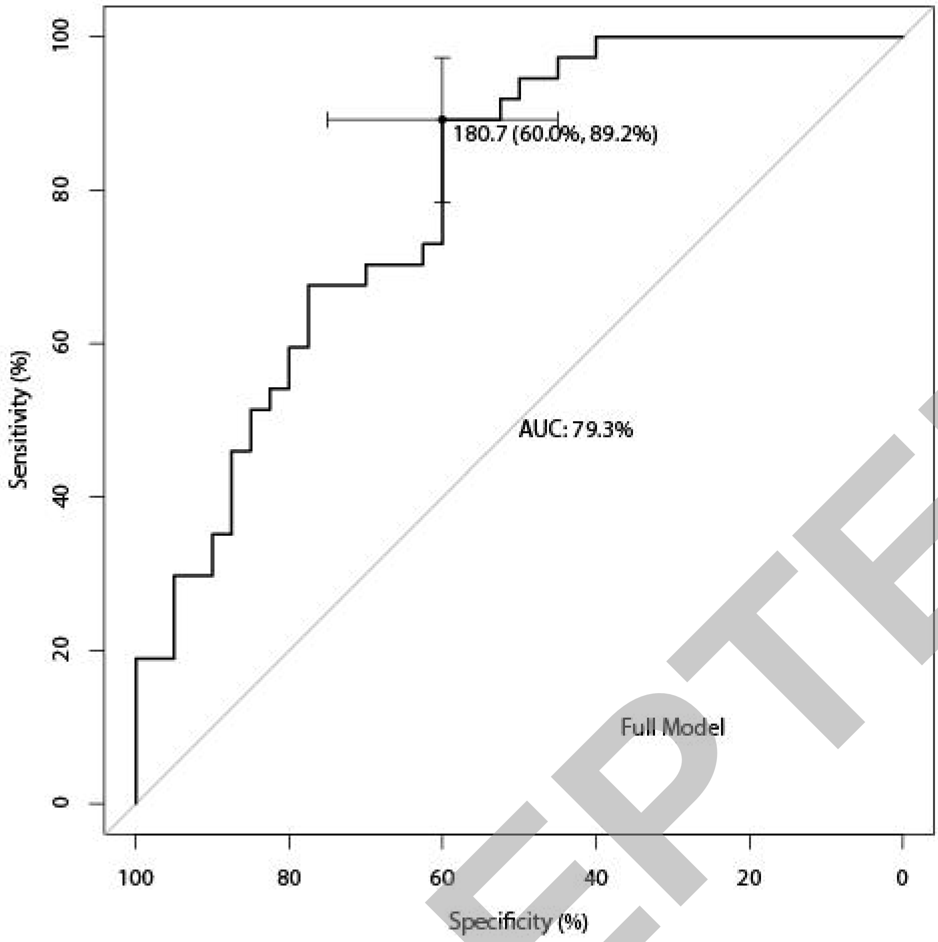
Note: * < 0.05; L left, R right; *d* effect size

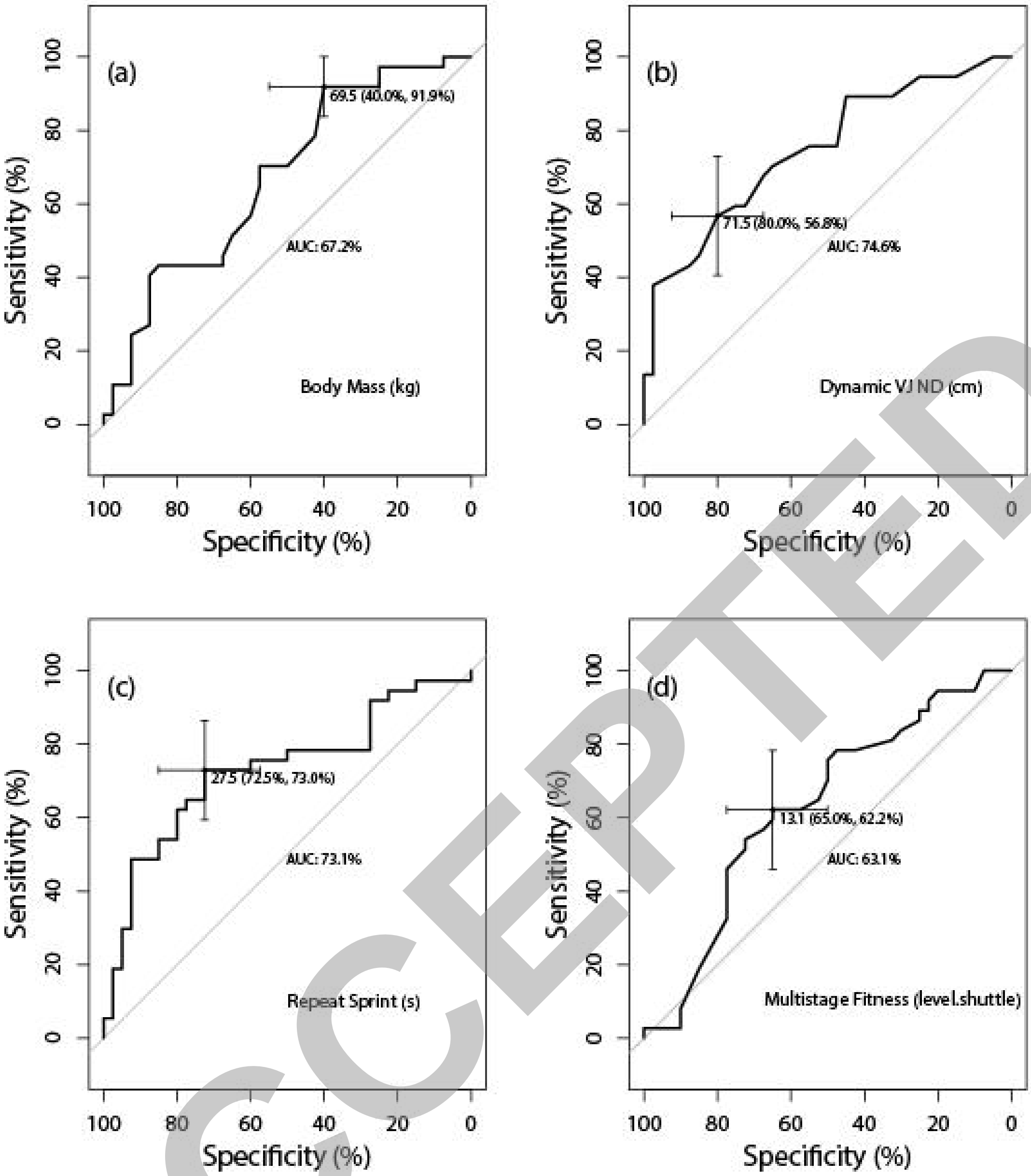
Table 3. Model summary for the physical fitness, anthropometric and movement competency assessments associated with developmental level ranked according to AICc

Predictors	*LL*	*df*	AICc	ΔAIC	w_i
~ BM + DVJND + RS + 20 m MSFT	**-34.99**	**5**	**80.84**	**<0.01**	**0.05**
~ Agility + BM + DVJND + RS + 20 m MSFT	-34.17	6	81.54	0.70	0.03
~ Agility + BM + DVJND + 20 m MSFT	-35.43	5	81.71	0.87	0.03
~ BM + DVJND + PuP + RS + 20 m MSFT	-34.53	6	82.27	1.43	0.02
~ Agility + BM + DVJND + PuP + 20 m MSFT	-34.65	6	82.51	1.67	0.02
~ BM + DVJND + RS + 20 m MSFT + SVJ	-34.76	6	82.73	1.89	0.02
Null (~1)	-53.31	1	108.68	27.84	<0.01

Note: BM, body mass; DVJ, dynamic vertical jump; ND, non-dominant; D, dominant; MSFT, multistage fitness test; PuP, push up; SVJ, stationary vertical jump


START
FINISH
2.5
2.5 m
2.5 m
Timing lights
Agility poles


180.7 (60.0%, 89.2%)
AUC: 79.3%
Full Model
Sensitivity (%)
Specificity (%)
100
80
60
40
20
0


(a)
69.5 (40.0%, 91.9%)
AUC: 67.2%
Body Mass (kg)
Sensitivity (%)
Specificity (%)
(b)
71.5 (80.0%, 56.8%)
AUC: 74.6%
Dynamic VJ ND (cm)
Sensitivity (%)
Specificity (%)
(c)
27.5 (72.5%, 73.0%)
AUC: 73.1%
Repeat Sprint (s)
Sensitivity (%)
Specificity (%)
(d)
13.1 (65.0%, 62.2%)
AUC: 63.1%
Multistage Fitness (level.shuttle)
Sensitivity (%)
Specificity (%)