Development of physical and skill training drill prescription systems for elite Australian Rules football

David M Corbett[1,2], Jonathan D Bartlett[1,2], Fergus O'Connor[1,2], Nicole Back[1], Lorena Torres-Ronda[1,3], & Sam Robertson[1,2]

[1] Institute of Sport, Exercise & Active Living (ISEAL), Victoria University, Australia

[2] Western Bulldogs Football Club, Footscray, Australia

[3] Department of Health and Kinesiology, Exercise and Sport Nutrition Lab, Texas A&M University, College Station, TX, USA

Corresponding author:

Associate Professor Sam Robertson, Institute of Sport, Exercise & Active Living, Victoria University PO Box 14428, Melbourne, Victoria, Australia, 8001

Tel: +61 399 194 204

Email: sam.robertson@vu.edu.au

Total Word Count: 4219

Abstract Word Count: 247

Number of Tables: 4

Number of Figures: 0

Abstract

Elite team sport athletes can undertake a limited amount of training each week. Consequently, designing training drills that improve both skilled and physical performance concurrently and efficiently is of high importance. This study developed three training drill classification systems using physical and skill-related data obtained from Australian Rules football training. Forty professional male athletes from a single elite Australian Rules football club were recruited for this study. All wore a 10 Hz Global Positioning System unit for six matches and 17 training sessions, which included a total of 35 different drills. High intensity running per minute, metres per minute and high intensity running as a percentage of total distance were obtained to provide a representation of each drill's physical requirements. Velocity at kick (moving or stationary), time in possession (greater or less than 2 seconds) and the presence of pressure was manually coded upon each kick to provide a representation of the constraints relating to each training drill. For the first prescription system, two *k*-means clustering algorithms were run on physical and skill data separately to identify similarities between training drills. For the second system, *z*-scores were calculated for each physical and skill characteristic in each training drill to compare directly with match conditions. For the third system, a 'Specificity Index' was calculated using the absolute average of the pooled *z*-scores for physical and skilled characteristics respectively. The three systems developed in this study can be used to aid training prescription in elite Australian Rules football.

Keywords: GPS, training drill design, conditioning

Introduction

Australian Rules football (AF) is a high intensity, intermittent contact sport, characterised by high cognitive and physical demands (Aughey, 2010, 2011; Boyd, Ball, & Aughey, 2013). Thus, training drills should provide a sufficient and relevant stimulus from both a physical and skill perspective, in order to improve or maintain conditioning (Aguiar, Botelho, Lago, Maças, & Sampaio, 2012; Foran, 2001; Hoffmann Jr, Reed, Leiting, Chieh-Ying, & Stone, 2014) and skilled performance (Davids, Renshaw, & Savelsbergh, 2010). Furthermore, drill prescription in team sports should aim to replicate match conditions as this will likely lead to a maximal transfer to skilled performance (Barris, Davids, & Farrow, 2013; Pinder, Davids, Renshaw, & Araújo, 2011), and have the greatest positive impact on physical conditioning (Gamble, 2004). In the research, training drills in AF have been presented as being prescribed exclusively based on their physical (Loader, Montgomery, Williams, Lorenzen, & Kemp, 2012) or technical-tactical requirements (Farrow, Pyne, & Gabbett, 2008). However, for a notably dynamic sport such as AF (Appleby & Dawson, 2002), a combined approach considering both forms of information appears warranted.

From a physical perspective, external load descriptors such as session duration, time spent in velocity zones and total distance covered are often used to design and prescribe training drills in team sports (Cummins, Orr, O'Connor, & West, 2013). Such information is now readily obtainable in near real-time, through the use of wearable technologies such as Global Positioning Systems (GPS) and inertial measurement units (Gastin, McLean, Spittle, & Breed, 2013Moreira, McGuigan, Arruda, Freitas, & Aoki, 2012). The use of these technologies has also allowed for quantification of the physical demands of competition (Cummins et al., 2013). It has been shown that elite AF players cover an average of 13.5 km per match of which, approximately 33% is covered at velocities greater than 14.4 km/hr, and complete an average of 2.1 high-speed efforts per minute (Johnston et al., 2012). In addition to this physical workload are sport-specific technical actions such as kicks, handballs, marking, tackling and bumping. Consequently, it would seem logical that both the physical and skill load components of competition are systematically considered as part of training prescription in order to expose players to match like training scenarios.

From a skill perspective, dynamical systems theories of skill acquisition have identified the constraints, or the boundaries, associated with human movement (Davids, Araújo, Shuttleworth, & Button, 2003; Ericsson & Lehmann, 1996). These constraints can be classified as relating to the individual (i.e., the characteristics of the performer such as their speed, height and weight), environment (including factors such as pressure, and characteristics of the physical environment) and task (the rules and requirements of a drill) (Magill, 2011). Consequently, identifying the key constraints in a given sport is vital to understanding and monitoring skill acquisition.

The time in possession a player has with the ball prior to skill execution represents an example of a task constraint in AF. In team sports when players must quickly dispose of the ball, they may be more likely to select an inappropriate target and/or perceive the task as more difficult (MacKenzie & Buxton, 1992; Mottet, Bootsma, Guiard, & Laurent, 1994). Similarly, the level and type of pressure on the skilled performance could be considered an example of an environmental constraint, as players may be more likely to make an error as they attempt to make space from the opposition (Panchuk & Vickers, 2006; Vilar, Araújo, Davids, Correia, & Esteves, 2013; Vilar, Araújo, Davids, & Travassos, 2012). The movement speed of a player at the time of skill execution provides an example of an individual constraint, as players experience less coordinated neuromuscular patterns and are more likely to miss their target in kicks executed at faster running speeds (Ball, 2008). Obtaining data with respect to how players respond when facing these constraints can provide enriching information in which to assist with the design of training drills. It also provides a means by which the specificity of a drill can be determined, by comparing directly with the conditions typically experienced in competition. For the purpose of this study, specificity is defined as the necessity of a "training programme to stress the systems that are involved in performing a particular activity to achieve specific training adaptations" (Reilly et al., 2009, p. 275).

The aim of this study was two-fold. First, this work aimed to develop three specificity-based methods to prescribe drills, using both their physical and skilled characteristics. Second, this study aimed to determine the extent of how commonly undertaken training drills at an elite AF club reproduce the physical and skill related conditions of competition.

Methods

Participants

A convenience sample of 40 professional males from a single Australian Football League (AFL) club was used for this study (age: 23 ± 4 years, height: 187 ± 8 cm, mass: 86 ± 9 kg). All athletes were uninjured, had available GPS data for selected training drills and participated in at least one AFL match. This was to ensure that load measures were typical of an elite Australian rules footballer and thus drills could be evaluated on their physical and skill characteristics. Informed written consent was obtained from all participants, with ethical approval supplied by the institutional Human Research Ethics Committee.

Data collection

This was a cross-sectional study conducted during the 2014-2015 seasons, with data collected over a 24 week period. For skill data this included all 22 AFL regular season matches along with 17 training sessions. For physical data, this included a total of six matches performed outdoors and the same 17 training sessions. Based on this, a total of 35 training drills were included in this study. These included a combination of conditioning-based drills, match simulation and small-sided games which are commonly used by many elite AF clubs. However a number of drills specific to the game style of the AF club were also included in the analyses.

For all field drills and matches, players wore 10 Hz global positioning system units (GPS) (Optimeye S5, Catapult, Catapult Sports Ltd, Melbourne). The devices were placed on the upper back of players in either a pouch sewn into their guernsey or using a harness. Players wore the same device during each match and training session to reduce the risk of inter-unit error (Johnston, Watsford, Kelly, Pine, & Spurrs, 2014). AFL matches were divided into four quarters, with interchanges recorded using the manufacturers' software package *Openfield* (Catapult Systems, Melbourne). This was done to ensure measures of intensity were not rendered inaccurate by including inactive time. Five physical measures were obtained from the GPS devices used in this study. These were: distance (m), metres per minute ($m \cdot min^{-1}$), high intensity running distance (HIR) [distances covered at speeds >4 $m \cdot s^{-1}$ (m)] (Coutts et al. 2010), $HIR \cdot min^{-1}$ and HIR as a percentage of total distance (HIR%). For training sessions, each individual drill was exported from an overall session video file and quantified through *Openfield*.

To obtain footage for analysis of skill conditions, training sessions were recorded using two digital cameras. The first camera (Canon XA25, Canon, Japan) was operated at a height of approximately 15 m and provided a side view of all training sessions. This camera followed the player in possession of the ball, as well as players within close proximity. The second camera (Canon XA20, Canon, Japan) was placed at a height of approximately 10 m and was placed behind the goals. This camera remained fixed and provided a wide view of all players in the session to capture any information missed by the first camera. For all matches, television broadcast footage was used to undertake notational analysis.

To examine the constraints associated with each kick, notational analysis software was used (Sportscode version 10.3.3, Serial number: 47454, Sportstec Inc., Warriewood NSW). Three skill measures were collected to provide a representation of this component of the match. Firstly, time in possession was obtained using Sportscode's timer feature. This was calculated as the time between the player first gaining possession and then disposing of the ball. Based on coach consultation, two categories were heuristically chosen for use in the study. Specifically, kicks were classified based on whether they were executed in less than or longer than two seconds following the player obtaining possession of the ball. Secondly, movement speed of the player at the time of kick execution was classified as either moving or stationary. For this interpretation, 'stationary' was defined as the player kicking from either a standing position (i.e., following a mark or free kick) or at a walking pace. Any movement speed higher than walking pace was considered as 'moving'. Third, the presence of pressure was defined as one or more opposition players within three metres of the athlete disposing of the ball. These three constraints provided examples of task, individual and environmental constraints respectively. The first and fourth author undertook coding of matches and training. Inter and intra-observer agreement was almost perfect for movement speed at kick and time in possession (inter-rater kappa coefficients: 0.83, 0.86, intra-rater; 0.89 and 0.89, 0.92 and 0.93 respectively), and was substantial for pressure (inter-rater: 0.76, intra-rater 0.89 and 0.82 for rater 1 and 2 respectively) (Hallgren, 2012).

Statistical analysis

Descriptive statistics (mean ± standard deviation) relating to each of the five physical and three skill characteristics were obtained for matches and each training drill. To determine the extent to which each of the 35 drills were similar to one another, two separate *k*-means cluster analyses (Jain, 2010) were undertaken for the physiological and skill characteristics respectively. Prior to this, a hierarchical cluster analysis (Bridges, 1966) was undertaken for each in order to identify the appropriate number of clusters for use in the analysis. The between-groups linkage and mean squared Euclidian distance were used to make this assessment, with the final selection chosen based on visual observation of a scree plot displaying these results for 34 possible cluster sizes (Mooi & Sarstedt, 2010). For the *k*-means clustering, each drill was assigned to a relevant group based on the proximity to the cluster centre.

For the second prescription system, *z*-scores (refer to Introduction) were obtained for each drill and characteristic based on their comparison with match demands. These comparisons were undertaken using mean data from the six GPS and 17 skill files obtained from competitive matches. To this end, this data was used to provide a representation of match demands for each physical and skill characteristic (Formula 1), with match conditions set to ‘1’ (or 100%) in the formula and a drill-to-match ratio ($d_{tm)}$ computed as the percentage of match conditions attained by each drill. This system was developed specifically to show the extent to which each drill represented match play with respect to its physical and skill characteristics. Therefore, a positive *z*-score inferred an increased presence of a given characteristic comparative to match conditions, with a negative value meaning a comparatively lower presence.

$$z_{\text{specificity}} = \frac{1-\mathrm{d}_{tm}}{\sigma_{drills}} \quad (1)$$

For the third prescription system, firstly a 'physical specificity index' was calculated using Formula 2.

$$Physical\ Specificity\ Index = \frac{\Sigma|z_{\text{specificity for physical characteristics}}|}{3} \quad (2)$$

This value gave the mean number of standard deviations a drill was away from the match mean across all three physical characteristics. This process was again repeated for skill characteristics to determine a 'skill specificity index' using Formula 3.

$$Skill\ Specificity\ Index = \frac{\Sigma|z_{\text{specificity for skill characteristics}}|}{6} \quad (3)$$

Unless otherwise stated, analyses were conducted using SPSS for Windows, Version 17.0 (IBM Corporation, Somers, New York, USA) with $P < 0.05$ indicating statistical significance in a two-tailed significance test.

Results

Drill prescription system I - Cluster analysis

Visual inspection of the hierarchical cluster pre-screening revealed that five clusters were appropriate for use in both the physical and skill analysis. Physical and skill cluster centres for each of the physical and skill characteristics are presented in Table I, with drill cluster membership in Table II. Cluster 1 drills averaged speeds one and a half times that of a match, with almost three times the amount of high-intensity running. Cluster 3 drills were characterized by the highest average metres per minute of all clusters, but with the lowest amount of high-intensity running. Clusters 2 and 5 had similar characteristics, with close to, or above match conditions in their physical characteristics respectively. Drills in Cluster 4 had the slowest disposal times, and required athletes to move the least.

This first prescription system also identified five types of drills based on their skill requirements. Cluster 1 drills had slightly more kicks performed under pressure than match conditions, but participants were slower in their disposal times and had lower kicks executed at running velocities. Drills in Cluster 2 had slower disposal times than a typical match, but had similar levels of pressure and fast velocities at kick. Drills in Cluster 3 had no kicks, as evidenced by the value of '0' for all constraints. This is because they were either conditioning or handball only drills. Cluster 4 drills had the fastest disposal times.

****INSERT Table I ABOUT HERE****

****INSERT Table II ABOUT HERE****

Drill prescription system II - z-score analysis

The standardised distance from match conditions for the physical characteristics of all drills is shown in Table III. The standardised distance from match conditions for all skill characteristics is shown in Table IV. The training drill *18 v 18* was the most specific, with z-scores for all physical and skill characteristics reported at 0.6 or lower. Tactical drills such as *Tackling drill* had the lowest physical specificity, whilst purely conditioning drills such as *4 min sub-max* more closely resembled matches in terms of movement demands.

****INSERT Table III HERE****

Drill prescription system III - specificity indices

The physical and skill 'Specificity Index' for each drill are presented in Table V. The specificity indices can be interpreted by the closer to zero, the more representative of match demands. The drill '18 v 18' showed a specificity index closest to zero for both skill and physical characteristics (0.17 and 0.19 respectively), suggesting a considerable similarity to match conditions. In contrast drills without a ball (i.e., *iPod*, *Speed/Agility, Jackal, 4 min sub-max* among others) unsurprisingly showed a lower resemblance to both the physical and skill characteristics of matches. Consequently, they showed the largest index values.

****INSERT Table IV HERE****

Discussion

The first aim of this study was to determine three separate systems for prescribing training in team sports, using information relating to the physical and skill demands of drills. The *k*-means clustering analysis identified five different types of drills for both their physical and skill characteristics. The *z*-score analysis quantified the specificity of training drills, by comparing both physical and skill characteristics to typical competition demands. The third method developed a Specificity Index, which determined a single value for each drill, thereby providing a method whereby practitioners can quickly assess the specificity of training drills based on their skill and physical characteristics.

In the first system, each of the five physical drill types can be prescribed to suit different training goals. Drills in Cluster 1 had a meterage per minute and level of high intensity running well above that of a match. Consequently, drills in this cluster such as *iPod* and *Jackal* tended to be high intensity conditioning drills, and are likely useful in building players' repeat effort ability (Ade, Harley, & Bradley, 2014). Whilst Cluster 2 drills were slightly below match levels for all characteristics, Cluster 5 drills showed slightly higher values. Consequently, both of these drill types may provide a load similar to a match, with Cluster 2 drills more desirable when a lower intensity is required (Gould & Dieffenbach, 2002). Drills in Cluster 4 had intensity well below that of a match, and are consequently most useful in minimising physiological load (Kellmann, 2010). Drills in Cluster 4 were also of a relatively low intensity, and tended to focus purely on technical skill refinement such as *Goal kicking* and *Diagonal kicking*. It is of note that the *Speed-agility* drill was also included in this cluster. This likely reflects a limitation of the measurement tools used in this study as these drills would likely have greater acceleration and deceleration requirements which were not included in the classification here. To further discriminate speed/agility drills from kicking-based drills, this type of information could be useful to consider in future, however this would require sensors additional to the GPS used in this investigation. As the validity and reliability of accelerometer use for this purpose increases (Cummins et al., 2013), such technologies could be incorporated, with resulting information added to improve the granularity of clusters.

Similarly, each of the five skill drill types could be used by coaches depending on the constraints and skills they aim to improve. Cluster 1 drills had slower disposal execution times and velocities at kick than a typical match, however the proportion of kicks executed under pressure was higher. Consequently, drills such as *9v9 game* and *Clear space* could be selected when responding to pressure is a key training objective. Drills in Cluster 2 were uniquely characterized by a greater proportion of moving kicks. Consequently, drills such as *18 v 18* and *3-phase footy* could be selected when disposing of the ball whilst running is a training focus. Many of the drills in this cluster tended to be games based, such as *5 v 6 defensive grid* and *18 v 18*. Both of these drills attempt match simulation, but did not replicate the time constraints of AF matches. Consequently, the task constraints of drills could be modified so as to increase their specificity index (Bennett & Davids, 1997). Cluster 4 drills had the fastest disposal times, and required athletes to modify their kicks to a range of different circumstances due to pressure. This included drills such as *Diagonal kick* and *Goal kicking*. Cluster 4 drills were also highly constrained; with fast disposal times, faster kicks and shorter possession times. Given that optimal skilled performance ensues after exposure to highly constrained drills, these drills are likely to have the highest transfer to performance (Magill, 2011). However, given that they are likely to possess a high cognitive load, they should also be used sparingly (Farrow et al., 2008).

Of the three systems presented, this first approach perhaps best allows users to select and design drills intuitively based on their descriptive characteristics. For example, if a drill with a low physiological load is desired, but also a high proportion of high-pressure situations, *Initiative square* could be determined as an appropriate solution. This system also assists users to develop training sessions which improve an athlete in multiple ways. The *k*-means analyses identified similarities between training drills, and consequently, if an athlete is exposed to only drills in one cluster, they are unlikely to meet all the requirements needed for competition.

The *z*-score analysis of drills seen in the second system can be specifically used by practitioners to identify the extent to which drills reflect match conditions. For example, if a coach was attempting to decide between prescription of *18 v18* or *8 v 8 stoppage game,* it could be noted that the former provides physical and skill-based stimuli more comparatively reflective of the demands of competition. This system also allows users to evaluate their training drills and identify the need for modification. In this sense, *18 v18* did not provide the same level of pressure and fast disposals as a typical match. Therefore, it may be necessary to manipulate the task constraints of the drill in order to make it more representative of match conditions. This could include introducing rules which limit disposal times to less than 2 seconds or provide specific instruction to certain players to exert high pressure to their teammates.

For the third system, both a physical and skill 'Specificity Index' were derived based on the output from the *z*-score analysis. Unlike the z-score analyses, the index provides a single absolute value, and therefore provides a concise insight into the properties of a drill. For example, if the Skill Specificity Index for a match was 0.1, this suggests that a training drill will more specifically prepare an athlete for an upcoming match from a skill perspective compared to a value of 1.0. This system also has implications for drill modification. For example, if a match play drill is monitored under this system and returns a Specificity Index far from 0, then the drill should be examined in closer detail (potentially using the second system) to increase its specificity to match conditions.

An advantage of the three systems developed in this study is that they are able to monitor the physical and skill characteristics of training drills concurrently. Previous studies investigating a similar topic (Loader et al., 2012), have not quantified the constraints within training drills, and inferred purely 'skill refining' drills in the absence of physiological intensity. This previous work utilised three clusters, which included; conditioning type drills, match play drills and skill refining drills. However, each prescription system in this study suggested the trade-off between physical and skill intensity was not as clear, and drills could have a wide range of physical and skill characteristics. The cluster analysis showed a diverse range of physical and skill characteristics, whilst the z-score analysis revealed high physical loads in skill drills such as *Jackal*, on part with conditioning drills such as *iPod.* As such, monitoring drills purely on their physical or skill characteristics is likely to lead to inappropriate prescription in one or more characteristics (Farrow et al., 2008). For example, observation of only the physical characteristics of the *18 v 18* and *Boxout* drills would suggest that both are extremely similar. However, from a skill perspective, one of these drills has a higher average time in possession than the other. This prescription system allows practitioners to evaluate these drills comprehensively and make a more informed decision about the drill they wish to prescribe.

The focus of this study was to develop a method to assess the specificity of training drills to match play so as to improve the efficiency of training drill prescription. Training specifically to the demands of the sport yields the greatest improvements in performance (Aguiar et al., 2012; Al-Abood, Davids, & Bennett, 2001; Guadagnoli & Bertram, 2014), yet, no evidence exists as to how specific training is to a particular sport. To our knowledge, the approach in this study is the first to demonstrate an integrated physical-skill training prescription tool that aligns training with match play in team sports. Although training design is likely to be coach-driven and prescribed specifically towards delivering a particular game style, it is likely that drill types and the physical-skill characteristics of each are inherent to a given squad of players. However, practitioners should aim to quantify particular game styles and align training so as to maximise game style physical and skill development.

The secondary aim of this study was to determine the extent of how commonly undertaken AF drills represent match demands. Each of the three prescription systems used in this study revealed a wide range in the specificity of training drills. As expected, skill-based drills such as *Tackling drill* and purely conditioning drills such as *Strides* did not reflect match demands. This is shown in their high z-scores across all characteristics and high specificity indices. Interestingly, even *18 v 18* (a drill which was designed to replicate match situations) showed slightly different characteristics to a typical match, with less kicks performed under pressure and fewer kicks being executed in less than two seconds. A drill such as *5 v 6 defensive grid*, on the other hand, was above a typical match in all characteristics bar pressure. These findings suggest that match-play drills may require modification to improve their specificity index.

There were limitations to this study which should be stated. Only drills which had one ball movement were used in the analysis. This meant that drills with two or greater ball movements were not analysed in this study. Different playing positions in AF are also likely to have varied physical and skill requirements. Consequently, future research may look to identify how different individuals respond to training drills, and provide a system that allows for position specific training. Further, other relevant team sport constraints, such as the prevalence of preferred/non-preferred limb and kick distance could be coded to provide a further refined prescription system in future.

Conclusions

This study adopted a three-phase approach to quantifying the physical and skill characteristics of training drills. The first phase identified five broad clusters of training drills in AF. This could be used to ensure a wide range of training drills are being prescribed, and to allow coaches to quickly select training drills based on their desired physical and skill characteristics. The second phase evaluated training drills based on how well each physical and skill characteristic resembled match conditions. This system could be used to select training drills through specific constraints of interest, and identify whether they need modification due to lack of specificity. The final phase developed a physical and skill Specificity Index, to identify how well training drills resembled match conditions across all physical or skill characteristics. This can be used to ensure match play drills are as specific as possible, and can be used in tandem with the other systems to identify the need for modification. Each of these systems provide an integrated approach to training drill prescription, to ensure training drills prepare athletes for both the physical and skill requirements of competition.

References

Ade, J. D., Harley, J. A., & Bradley, P. S. (2014). Physiological response, time-motion characteristics, and reproducibility of various speed-endurance drills in elite youth soccer players: small-sided games versus generic running. *International Journal of Sports Physiology and Performance, 9*(3), 471-479

Aguiar, M., Botelho, G., Lago, C., Maças, V., & Sampaio, J. (2012). A review on the effects ofsoccer small-sided games. *Journal of Human Kinetics, 33*, 103-113

Al-Abood, S. A., Davids, K., & Bennett, S. J. (2001). Specificity of task constraints and effects of visual demonstrations and verbal instructions in directing learners' search during skill acquisition. *Journal of Motor Behavior, 33*(3), 295-305

Appleby, B., & Dawson, B. (2002). Video analysis of selected game activities in Australian rules football. *Journal of Science and Medicine in Sport, 5*(2), 129-142

Aughey, R. J. (2010). Australian football player work rate: evidence of fatigue and pacing. *International Journal of Sports Physiology and Performance, 5*(3), 394-405

Aughey, R. J. (2011). Increased high-intensity activity in elite Australian football finals matches. *International Journal of Sports Physiology and Performance, 6*(3), 367-379

Ball, K. (2008). Biomechanical considerations of distance kicking in Australian Rules football. *Sports Biomechanics, 7*(1), 10-23.

Barris, S., Davids, K., & Farrow, D. (2013). Representative learning design in springboard diving: Is dry-land training representative of a pool dive? *European Journal of Sport Science, 13*(6), 638-645

Bennett, S., & Davids, K. (1997). The effect of task constraints on the manipulation of visual information and the implications for the specificity of learning hypothesis. *Human Movement Science, 16*(4), 379-390

Boyd, L. J., Ball, K., & Aughey, R. J. (2013). Quantifying external load in Australian Football matches and training using accelerometers. *International Journal of Sports Physiology and Performance, 8*(1), 44-51

Bridges, C. C. (1966). Hierarchical cluster analysis. *Psychological Reports*, 18(3), 851-854.

Cummins, C., Orr, R., O'Connor, H., & West, C. (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. *Sports Medicine, 43*(10), 1025-1042

Davids, K., Araújo, D., Shuttleworth, R., & Button, C. (2003). Acquiring skill in sport: a constraints led perspective. *International Journal of Computer Science in Sport, 2*(2), 31-39

Davids, K., Renshaw, I., & Savelsbergh, G. J. P. (2010). *Motor learning in practice : a constraints-led approach*: London ; New York : Routledge, 2010. 1st ed.

Ericsson, K. A., & Lehmann, A. C. (1996). Expert and exceptional performance: Evidence of maximal adaptation to task constraints. *Annual Review of Psychology, 47*(1), 273-305

Farrow, D., Pyne, D., & Gabbett, T. (2008). Skill and physiological demands of open and closed training drills in Australian football. *International Journal of Sports Science and Coaching, 3*(4), 489-499

Foran, B. (2001). *High-performance sports conditioning*: Human Kinetics: Champaign.

Gamble, P. (2004). A Skill-based conditioning games approach for elite rugby football players. *Journal of Strength and Conditioning Research, 18*(3), 491-497

Gastin, P. B., McLean, O., Spittle, M., & Breed, R. V. P (2013). Quantification of tackling demands in professional Australian football using integrated wearable athlete tracking technology. *Journal of Science and Medicine in Sport, 16*(6), 589-593.

Gould, D., & Dieffenbach, K. (2002). Overtraining, underrecovery, and burnout in sport. *Enhancing recovery: Preventing underperformance in athletes*, 25-35

Guadagnoli, M. A., & Bertram, C. P. (2014). Optimizing practice for performance under pressure. *International Journal of Golf Science, 3*(2), 119-127

Hallgren, K. A. (2012). Computing inter-rater reliability for observational data: an overview and tutorial. *Tutorials in Quantitative Methods for Psychology, 8*(1), 23

Hoffmann Jr, J. J., Reed, J. P., Leiting, K., Chieh-Ying, C., & Stone, M. H. (2014). Repeated sprints, high intensity interval training, small sided games: theory and application to field sports. *International Journal of Sports Physiology and Performance, 9*(2), 352-357

Jain, A. K. (2010). Data clustering: 50 years beyond *k*-means. *Pattern Recognition Letters*, 31(8), 651-666.

Johnston, R. J., Watsford, M., Pine, M., Spurrs, R., Murphy, A., & Pruyn, E. (2012). Movement demands and match performance in professional Australian football. *International Journal of Sports Medicine, 33*(2), 89-93

Johnston, R. J., Watsford, M. L., Kelly, S. J., Pine, M. J., & Spurrs, R. W. (2014). Validity and interunit reliability of 10 Hz and 15 Hz GPS units for assessing athlete movement demands. *The Journal of Strength and Conditioning Research, 28*(6), 1649-1655

Kellmann, M. (2010). Preventing overtraining in athletes in high- intensity sports and stress/recovery monitoring. *Scandinavian Journal of Medicine and Science in Sports, 20*(s2), 95-102

Loader, J., Montgomery, P. G., Williams, M. D., Lorenzen, C., & Kemp, J. G. (2012). Classifying training drills based on movement demands in Australian Football. *International Journal of Sports Science and Coaching, 7*(1), 57-68

MacKenzie, I. S., & Buxton, W. (1992). Extending Fitts' law to two-dimensional tasks *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 219-226): ACM.

Magill, R. A. (2011). *Motor learning and control : concepts and applications*: New York: McGraw-Hill.

Mooi, E., & Sarstedt, M. (2010). *Cluster analysis.* Berlin: Springer.

Moreira, A., McGuigan, M. R., Arruda, A. F., Freitas, C. G., & Aoki, M. S. (2012). Monitoring internal load parameters during simulated and official basketball matches. *The Journal of Strength and Conditioning Research*, *26*(3), 861-866

Mottet, D., Bootsma, R. J., Guiard, Y., & Laurent, M. (1994). Fitts' law in two-dimensional task space. *Experimental Brain Research, 100*(1), 144-148

Panchuk, D., & Vickers, J. (2006). Gaze behaviors of goaltenders under spatial–temporal constraints. *Human Movement Science, 25*(6), 733-752

Pinder, R. A., Davids, K., Renshaw, I., & Araújo, D. (2011). Representative learning design and functionality of research and practice in sport. *Journal of Sport and Exercise Psychology, 33*(1), 146-155

Reilly, T., Morris, T., & Whyte, G. (2009). The specificity of training prescription and physiological assessment: A review. Journal of Sports Sciences, 27(6), 575-589.

Vilar, L., Araújo, D., Davids, K., Correia, V., & Esteves, P. T. (2013). Spatial-temporal constraints on decision-making during shooting performance in the team sport of futsal. *Journal of Sports Sciences, 31*(8), 840-846

Vilar, L., Araújo, D., Davids, K., & Travassos, B. (2012). Constraints on competitive performance of attacker–defender dyads in team sports. *Journal of Sports Sciences, 30*(5), 459-469

Table I. Drill prescription system I - cluster centres for each characteristic

	1	2	3	4	5	Match
Metres per minute ($m \cdot min^{-1}$)	200.4	116.4	204.1	49.0	140.5	**130.5**
HIR per minute ($HIR \cdot min^{-1}$)	144.1	17.3	0.5	1.9	87.8	**33.5**
HIR as % of total distance (HIR % distance)	0.72	0.15	0.00	0.04	0.62	**0.26**
Kicks under no pressure (%)	0.13	0.33	0.00	0.00	0.22	**0.27**
Kicks under pressure (%)	0.79	0.67	0.00	0.00	0.78	**0.73**
Moving kicks (%)	0.38	0.66	0.00	0.69	0.74	**0.61**
Stationary kicks (%)	0.29	0.34	0.00	0.31	0.26	**0.39**
Kicks executed in < 2 sec (%)	0.17	0.31	0.00	0.68	0.74	**0.49**
Kicks executed in > 2 sec (%)	0.25	0.69	0.00	0.32	0.26	**0.51**

Table II. Drill prescription system I – skill and physical group membership for the 35 training drills included in the *k*-means cluster analyses

Physical cluster number	**Physical cluster membership**	**Skill cluster number**	**Skill cluster membership**
1	iPod, Jackal	1	9 v 9 game, Clear space, Corridor footy, Handball games, Tackling drill
2	18 v 18, 8 v 8 stoppage game, Anticipate turnover, Box out, Down the line/shape, Grid drill, Initiative square, Match play, Roundabout, Runaway breakdown, Shape to forwards, Shape to goal, Shape to rebound, Stoppage to forwards	2	18 v 18, 3-phase footy, 5 v 6 defensive grid, 8 v 8 stoppage game, Anticipate turnover, CBD, Centre bounce drill, Down the line/shape, Grid drill, Jackal, Kicking games A, Match play, Runaway breakdown, Shape to forwards, Shape to goal, Stoppage to forwards
3	4 min sub-max, Handball games	3	4 min sub-max, HB games, HG Bulldog ball, iPod, Speed agility, Strides
4	Diagonal kick, Goal kicking, HB games, HG bulldog ball, Speed agility, Tackling drill	4	Diagonal kick, Goal kicking, Roundabout
5	3-phase footy, 5 v 6 defensive grid, 7 v 4 keepings off, 9 v 9 game, CBD, Centre bounce drill, Clear space, Corridor footy, Down the line, Kicking games A, Strides	5	7 v 4 keepings off, Box out, Down the line, Initiative square, Shape to rebound

Table III. Drill prescription system II - specificity *z*-scores: skill and physical characteristics

	Physical characteristics			Skill characteristics		
Drill name	$m \cdot min^{-1}$	$HIR \cdot min^{-1}$	HIR/% distance	% kicks under pressure	% moving kicks	% kicks < 2 secs
18 v 18	-0.21	0.08	0.21	-0.09	0.11	-0.53
3-phase footy	-0.46	0.67	1.24	0.19	0.25	-0.72
4 min sub-max	1.89	-1.07	-1.39	-2.17	-2.11	-1.70
5 v 6 defensive grid	0.42	0.14	0.00	-0.20	0.23	0.01
7 v 4 keepings off	0.20	0.48	0.50	0.17	0.10	1.05
8 v 8 stoppage game	-0.20	-0.30	-0.32	-0.14	0.17	-0.28
9 v 9 game	0.58	1.03	0.99	-0.67	-0.80	-1.12
Anticipate turnover	-0.96	-0.60	-0.53	-0.56	-0.23	-1.04
Box out	-0.89	-0.31	-0.04	0.46	0.43	1.30
CBD	-0.26	1.27	1.90	-0.29	-0.18	-0.68
Centre bounce drill	-0.67	1.11	2.15	-0.40	0.10	-1.70
Clear space	0.11	0.25	0.26	-0.24	0.08	-1.70
Corridor footy	-0.48	0.73	1.34	0.16	0.17	-0.13
Diagonal kick	-2.02	-0.97	-1.04	-2.17	0.51	0.37
Down the line	0.07	0.29	0.33	0.25	0.25	0.17
Down the line/shape	-0.45	0.01	0.23	0.24	0.33	-0.51
Goal kicking	-1.02	-0.64	-0.58	-2.17	-0.29	1.56
Grid drill	-0.49	-0.07	0.14	-0.57	-0.16	-1.14
Handball games	2.03	-0.36	-0.24	0.83	-0.37	0.09
HB games	-1.90	-0.84	-0.66	-2.17	-2.11	-1.70
HG Bulldog ball	-1.45	0.09	1.30	-2.17	-2.11	-1.70
Initiative square	-0.68	-0.04	0.30	0.23	1.27	1.65
iPod	1.80	3.60	2.53	-2.17	-2.11	-1.70
Jackal	1.45	2.71	2.00	-0.10	0.19	-0.78
Kicking games A	0.37	0.33	0.24	-0.14	-0.08	-0.68
Match play	-1.08	-0.12	0.45	0.11	-0.37	-0.09
Roundabout	-0.35	-0.52	-0.59	-2.17	0.65	0.29
Runaway breakdown	-0.64	-0.29	-0.13	-0.07	0.70	-0.48
Shape to forwards	-0.38	0.34	0.62	-0.03	0.38	-0.62
Shape to goal	-0.56	0.22	0.63	-0.67	0.87	-1.70
Shape to rebound	-0.80	-0.22	0.07	-0.27	0.19	0.46
Speed agility	-1.10	-0.99	-1.21	-2.17	-2.11	-1.70
Stoppage to forwards	-0.76	0.03	0.47	-0.22	0.40	-0.12
Strides	0.26	1.77	2.02	-2.17	-2.11	-1.70
Tackling drill	-2.08	-1.02	-1.19	0.83	-2.11	-1.70

Notes: HIR is high intensity running, $m \cdot min^{-1}$ is metres per minute

Table IV. Drill prescription system III - specificity indices

Physical	Specificity Index	Skill
18 v 18; 5 v 6 Defensive grid	0.1 - 0.2	18 v 18; 5 v 6 defensive grid; Corridor footy
Clear space; Down the line; Down the line/shape; Grid drill; 8 v 8 stoppage game	>0.2 - 0.3	8 v 8 stoppage game; Down the line; Stoppage to forwards
Kicking games A; Initiative square; Runaway breakdown; Shape to rebound; 7v4 keepings off	>0.3 - 0.4	Kicking games A; Shape to rebound; Shape to forwards; Down the line/shape; Jackal; CBD; 3-phase footy
Box out; Stoppage to forwards; Shape to forwards; Shape to goal; Roundabout	>0.4 - 0.5	Runaway breakdown; Handball games; 7 v 4 keepings off
	>0.5 - 0.6	Anticipate turnover; Grid drill; Clear space
	>0.6 - 0.7	Anticipate turnover; Grid drill; Clear space
Anticipate turnover; Goal kicking; 3-phase footy	>0.7 - 0.8	Box out; Centre bounce drill
Corridor footy; 9 v 9 game; Handball games	>0.8 - 0.9	9 v 9 game
HG Bulldog ball	>0.9 - 1.1	Diagonal kick; Roundabout; Shape to goal
Speed agility; HB games; CBD; Centre bounce drill; Diagonal kick; Strides; Tackling drill; 4 min sub-max	>1.1 - 1.5	
	>1.5 - 2	Tackling drill; 4 min sub-max; HB games; HG Bulldog ball; iPod; Speed agility; Strides
Jackal; iPod	>2	