Review Paper

Activity profiles of elite netball umpires: A review

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ABSTRACT

This review has outlined the existing literature relating to activity profiles in elite netball umpires. In particular, the physical (distance travelled), physiological (heart rate), and technical (movement classifications) characteristics have been described. The limited available literature report that on average elite netball umpires travel approximately 3850 m during a 60 min match. Up to approximately 50% of the match is spent standing, with only around 25% of the match in higher intensity movements such as jogging, sprinting, side stepping, or changing direction. Work:rest ratios are typically approximately 1:3 during match play, with additional recovery in the intervals between quarters. This includes an average of 140 sprints for a duration of 2.8 s. Elite umpires spend around 10% of the match at greater than 92% peak heart rate, with the majority (approximately 55%) between 75 and 92% peak heart rate. These characteristics may benefit umpires and strength and conditioning practitioners when designing training programmes. The literature also report a reduction in distance travelled by elite umpires as the match progresses. An accompanying decrease in heart rate suggests that this is not caused by physiological fatigue mechanisms but is a result of technical adjustments in the movement patterns utilised. Indeed, elite umpires tend to sidestep less and walk or stand more as the match progresses. Additionally, gaps in the existing literature have been highlighted, including the relationship between perceptual-cognitive processes and movement, and the application of fitness testing requirements to umpire activity profiles. **Keywords:** Officiating; Referee; Movement; Global positioning system; Heart rate.

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INTRODUCTION

Netball is a 60 min (4 x 15 min) invasion ball game played between two teams of seven players on an indoor sprung wooden surface measuring 30.5 m x 15.25 m. The team with the ball attempts to move the ball into its goal circle, through running, jumping, throwing and catching, from where a goal may be scored. Uniquely, a player who has possession of the ball must release the ball within 3 s, and after doing so, may not replay the ball until it has been touched by another player or it rebounds from the goalpost. This, in combination with the requirement to throw or shoot before re-grounding the landing foot, makes for an exciting, fast, and skilful game in which the ball moves around the court at speed (International Netball Federation, 2015).

It is the responsibility of the two umpires to apply the Rules of the Game with impartiality, fairness and consistency. Each umpire controls and gives decisions for one half of the court including the goal line, plus decisions for the throw in on one side line. For this purpose, the length of the court is divided in half across the centre from side line to side line (Figure 1) (International Netball Federation, 2015). During a match, each umpire will utilise a range of movement techniques, including walking, jogging, sidestepping, changing direction, and sprinting to move around their allocated side line and goal line (Otago, Riley, & Forrest, 1994; Spencer, Paget, Farley, & Kilding, 2019). In contrast to officials in some other sports, the division of the court also necessitates that umpires stand in a co-operative role whilst play is in their co-umpire's area of control.

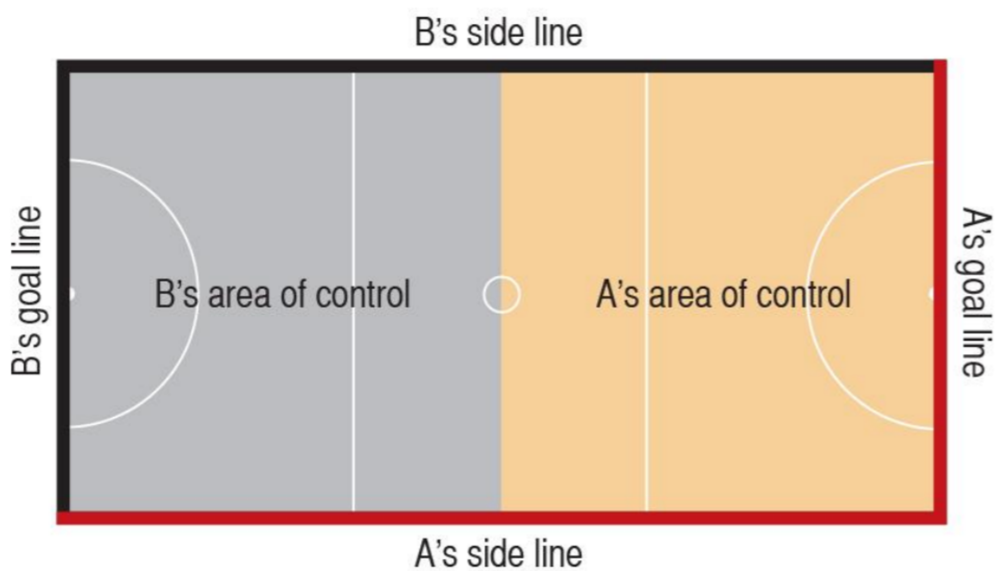

Figure 1. Umpires' areas of control. International Netball Federation (2015).

For elite netball matches to be officiated at the highest standard possible, and therefore have the fairest outcome (Mclean et al., 2019), umpires must strive for optimal performance. Numerous studies in invasion ball sports officiating have highlighted the importance of officials' positioning for decision making accuracy. For example, international association football referees have shown the lowest error rates for the central area of the field when viewing incidents from distances between 11 and 15 m, with viewing distance unrelated to decision accuracy in lateral areas of the field (Mallo, Frutos, Juárez, & Navarro, 2012). Additionally, FIFA World Cup referees had a 2.6 times greater risk of false whistle errors from viewing distances of 10 to 15 m, with a 5.5 times greater risk of false non-whistle errors from viewing distances of 0 to 5 m (Hossner, Schnyder, Schmid, & Kredel, 2019). Viewing angle was unrelated to decision making accuracy. As Gibson (p. 223) seminally argued, “We must perceive in order to move, but we must also move in order to perceive” (Gibson, 1979). Consequently, the positioning and timing of a netball umpire is an Important aspect of performance.

To characterise optimal performance and to aid in assessment and training methodologies, it is necessary to determine the specific requirements of an umpire. Of the multiple interrelated performance components that can be investigated (*e.g.* perceptual skills, decision making accuracy), this review will focus on physical, physiological, and technical parameters.

PHYSICAL

Physical movement parameters can be analysed similarly to those of players; however, modifications to the specific parameters are occasionally required due to the lack of ‘on the ball’, defensive or attacking movements. Distance travelled by officials has been calculated using video footage, and more recently Global Positioning Systems (GPS) within matches. Calculated parameters include total distance travelled in a match and distance travelled per discrete movement classification.

In the first study to assess activity profiles of netball umpires, Otago et al. (Otago et al., 1994) estimated distance travelled through analysis of video footage in relation to the court dimensions. This analysis was limited to a single A-grade (state to national level) umpire during a single match. This umpire was estimated to have travelled a total of 3850 m, including 970 m, 1050 m, 850 m, and 980 m during quarters one to four respectively. The large variation between quarters suggests an imbalance in either playing standard or playing style between the two teams: the umpire covered more distance during quarters two and four (when one team was attacking in their area of control) than during quarters one and three (when the other team was attacking in their area of control). Furthermore, video-based distance estimation may lead to variability in results due to distance estimation by the analyst. These results may therefore be considered unreliable, especially as no reliability test was completed within the study. As such, this data from a single match may not be representative of elite netball umpiring. It is nonetheless useful as a comparison for more recent and/or more detailed investigations.

Despite the methodological limitations, that study’s (Otago et al., 1994) total distance covered is remarkably similar (Table 1) to the results of the only other study to record physical movement parameters of elite netball umpires (Spencer et al., 2019). This study recorded 22 New Zealand high performance umpires (n = 9 ANZ Championships squad; n = 6 National A squad; n = 7 National development squad). GPS tri-axial accelerometer data (100 Hz; Minimax S4, Firmware 6.70, Catapult Innovations, Melbourne, Australia) was recorded during matches of the 2012 season, resulting in a total of 107 data sets. Due to the absence of satellite coverage during indoor matches, distance travelled was estimated as a secondary metric of Accumulated Player Load™ for each quarter and full match. Player Load™ was originally developed by the Australian Institute of Sport for rugby union (Catapult, Victoria, Australia) and has since been utilised as a measure of exertion in team sports (Gastin, McLean, Spittle, & Breed, 2013; Weston, Siegler, Bahnert, McBrien, & Lovell, 2015; Young, Hepner, & Robbins, 2012). Player Load™ has been shown to be reliable (field between device coefficient of variation 1.9%) (Boyd, Ball, & Aughey, 2011) and to correlate to distance covered via GPS measurement ($r = 0.95$) (Aughey, 2011) when the main activity is running and so was deemed appropriate for Spencer et al’s (2019) investigation of netball umpires. Estimated equivalent distance for an entire match averaged 3839 ± 614 m, with significantly less distance covered during quarter four compared to quarter two (934 ± 192 m *vs* 982 ± 182 m; $p = 0.03$; $d = 0.3$). 972 ± 169 and 951 ± 165 m were covered on average during quarters one and three respectively (Table 2).

Table 1. A comparison of two studies reporting physical, physiological, and technical parameters (mean ± s.d.) for netball umpires per 60 min match.

Otago et al., 1994		study	Spencer et al., 2019
3		**n**	22
24		**matches**	48
A-grade (state to national level)		**ability**	9 x ANZ Championships 6 x National A Squad 7 x National Development Squad
3850 (n = 1, 1 match)		**distance travelled (m)**	3840 ± 708
higher standard matches	lower standard matches	**match standard**	all combined
25.0 (combined)	11.6 (combined)	**time < 60% HRpeak (%)**	3 ± 8
		time 60-75% HRpeak (%)	25 ± 23
12.5	46.7	**time 75-85% HRpeak (%)**	34 ± 8
12.0	32.7	**time 85-93% HRpeak (%)***	20 ± 26
50.5	9.0	**time > 93% HRpeak (%)#**	9 ± 17
54 (combined)		**time walking sideways (%)**	10 ± 3
		time walking backward (%)	3 ± 2
		time walking forward (%)	15 ± 5
21		**time standing (%)**	49 ± 7
8		**time jogging (%)**	5 ± 2
5		**time sidestepping or turning to change direction (%)**	4 ± 2
12		**time sprinting (%)**	10 ± 2

*HRpeak: peak heart rate; *: time 85-92% HRpeak (%) for Otago et al., 1994; #: time > 92% HRpeak (%) for Otago et al., 1994.*

Table 2. A comparison of distance and heart rate demands (mean ± s.d.) during each quarter for netball umpires in Spencer et al.'s (2019) study.

	quarter 1	quarter 2	quarter 3	quarter 4
estimated equivalent distance (m)	972 ± 169	982 ± 182‡	951 ± 165	934 ± 192$^{\#}$
mean heart rate (b·min^{-1})	157 ± 13‡	156 ± 12‡	154 ± 13	153 ± 14$^{*\#}$
mean % HRpeak	81 ± 8$^{\$\ddagger}$	81 ± 7‡	80 ± 7*	79 ± 8$^{*\#}$
time < 60% HRpeak (%)	3 ± 6	3 ± 7	4 ± 7	4 ± 10
time 60-75% HRpeak (%)	21 ± 23$^{\#\$\ddagger}$	24 ± 20*‡	27 ± 24*	28 ± 23$^{*\#}$
time 75-85% HRpeak (%)	33 ± 20	32 ± 15	37 ± 19	35 ± 19
time 85-93% HRpeak (%)	31 ± 22$^{\$\ddagger}$	27 ± 19	24 ± 19*	24 ± 21*
time > 93% HRpeak (%)	9 ± 17	11 ± 18$^{\$\ddagger}$	8 ± 17$^{\#}$	7 ± 14$^{\#}$

*HRpeak: peak heart rate; *: significantly different to quarter 1; #: significantly different to quarter 2; $: significantly different to quarter 3; ǂ: significantly different to quarter 4.*

When considering differences in activity profiles of umpires between quarters one must recall the requirement for umpires to move in relation to the play on court. Studies investigating the activity profiles of different playing positions during elite netball competition (*e.g.* UK Netball Superleague (Davidson & Trewartha, 2008); Australian national team (Fox, Spittle, Otago, & Saunders, 2013)) have failed to report values for individual quarters or halves of the match. However, Cormack et al. (2014) did report such values for two lower standards of competition (Cormack, Smith, Mooney, Young, & O'Brien, 2014). Comparing first and second half Player Load™ data, there were no differences for Victorian state league players of any court area (shooters, centre court players, defenders). Contrastingly, centre court players at a lower recreational B grade standard showed a reduction in Player Load™ from the first to second half. Comparing individual quarters, the only difference at state league standard was a reduction in activity by shooters between quarter one and quarter four. At the recreational level, centre court players exhibited greater activity levels in the first quarter than all other quarters. It may be reasonable to assume that at an even higher standard than the state league matches investigated by Cormack et al. (2014), players would likely maintain intensity throughout the match (Cormack et al., 2014). As such, the reduction in distance covered by elite umpires between the second and fourth quarter may be due to either umpire fatigue (physiological measures) or improvements in the ability to anticipate styles of play on court and minimise unnecessary movements (technical measures).

PHYSIOLOGICAL

The most commonly measured physiological variable in sports officials is heart rate, which can be monitored to provide information including maximum, mean, and minimum heart rate, as well as the time spent in heart rate zones corresponding to different energy systems. Otago et al. (1994) recorded heart rate data for three Australian A-grade umpires for a total of 24 matches (8 ± 3 per umpire) (Otago et al., 1994). Peak heart rate was determined for each umpire via a maximal multi-stage fitness test (Ramsbottom, Brewer, & Williams, 1988) and used to define four individual heart rate zones: Zone 1 'Aerobic and Anaerobic Endurance' > 92% peak heart rate; 85% < Zone 2 'Anaerobic Threshold' ≤ 92%; 75% < Zone 3 'Aerobic Endurance' ≤ 85%; Zone 4 'Recovery and Regeneration' ≤ 75%. In the highest standard matches, the umpires spent 50.5%, 12.0%, 12.5%, and 25.0% of the time in heart rate zones 1 to 4 respectively. In lower standard matches the umpires spent 9.0%, 32.7%, 46.7%, and 11.6% of the time in heart rate zones 1 to 4 respectively (Table 1). Interestingly, the umpires spent far greater time in the highest and lowest heart rate zones during the higher standard matches. The fact that on average over half of the higher standard match was spent with a heart rate over 92% of peak heart rate underlines the importance of conditioning for elite netball umpires.

More recently, Spencer et al. (2019) used a similar approach in their analysis of the 22 New Zealand high performance umpires (Spencer et al., 2019). Peak heart rate for each umpire was determined from a Level One Yo-Yo Intermittent Recovery Test (Krustrup et al., 2003) as part of routine pre-season fitness testing. Heart rate zones were defined according to a previous study of Premier League association football referees (Weston, Castagna, Helsen, & Impellizzeri, 2009): A ≤ 60% peak heart rate; 60% < B ≤ 75%; 75% < C ≤ 85%; 85% < D ≤ 93%; E > 93%. Mean heart rate for the entire match was 155 ± 12 beats·min^{-1}, with mean heart rate during quarter 4 (153 ± 14 beats·min^{-1}) significantly less than quarters one (157 ± 13 beats·min^{-1}) and two (156 ± 12 beats·min^{-1}). Mean heart rate during the third quarter was 154 ± 13 beats·min^{-1} (Table 2). Umpires on average spent 3 ± 8%, 25 ± 23%, 34 ± 8%, 20 ± 26%, and 9 ± 17% of the match in heart rate zones A to E respectively. The 9% of time above 93% peak heart rate in Spencer et al.'s study much more closely resembles Otago et al's lower standard (9.0% above 92% peak heart rate) rather than higher standard (50.5% above 92% peak heart rate) matches (Table 1) (Otago et al., 1994; Spencer et al., 2019). It may be suggested, therefore, that the conditioning of umpires had improved between the two studies (from 1994 to 2012) leading to a reduction in the relative demands of elite matches.

Spencer et al. (2019) also compared the time spent in each heart rate zone between the four quarters of the matches (Spencer et al., 2019). It is of note that elite umpires generally spent less time at higher heart rates and more time at lower heart rates as the matches progressed (Table 2). The umpires spent less time in zone B in quarter one than all other quarters (and less time in quarter two than quarter four). Compared to quarters three and four, they also spent more time in zone D in quarter one and more time in zone E in quarter two. This analysis of differences between quarters suggests that the umpires did not suffer from fatigue as the matches progressed and that any concurrent reduction in distance covered may have been due to the utilisation of more efficient movement patterns, perhaps due to improvements in the perceptual-cognitive ability to anticipate styles of play on court (Guillén & Feltz, 2011).

It must also be considered that umpire movement is not the only factor to influence heart rate during a match. Indeed, heart rate may vary as a function of umpire arousal levels. One study of 10 cricket umpires (6 provincial umpires and 4 international umpires) measured heart rate in response to events in limited-overs cricket matches (Stretch, Tyler, & Bassett, 1998). Heart rate varied from 68 to 139 beats·min^{-1} with little locomotive movement involved. For example, the highest heart rate was recorded when one international umpire showed an increase from 121 to 139 beats·min^{-1} 15 s after an appeal for a catch that he gave 'not-out'. Another international umpire showed an increase from 89 to 106 beats·min^{-1} during a hat-trick (three wickets in three balls) despite not being required to make a decision as all three batsmen were bowled. Further research is needed to determine the relationship between decision making and heart rate in elite netball umpires, including the effect that heart rate has on decision making accuracy. For example, decision-making accuracy was unrelated to heart rate in five New Zealand Championship association football referees (Mascarenhas, Button, O'Hare, & Dicks, 2009). It may be necessary to seek alternative measures of intensity during netball umpiring.

TECHNICAL

Movement patterns can be used to assess intensity via the frequency and duration of high intensity movements such as sprinting and jogging in comparison to lower intensity movements such as standing or walking. Movement Pattern data collection has typically been completed via time-motion studies and analysed with notational analysis. Otago et al. (1994) used six movement classifications for their notational analysis of the three Australian A-Grade umpires' 24 matches: standing; walking; jogging; sprinting; side stepping; and changing direction (Otago et al., 1994). Umpires spent 54% of the match walking (forward, backward, or sideways), 21% standing, 12% sprinting, 8% jogging, and the remaining 5% either side stepping or changing direction (Table 1). Although sprinting and jogging were much less frequent than standing and walking (193 occurrences on average per match compared to 349), greater distance was travelled during these higher intensity movements. Distance covered during each sprint and jog averaged 10.7 m and 7.0 m respectively, in comparison to 5.5 m for the average walk. It should be noted that no reliability test was performed for this analysis.

In a similar notational analysis, Spencer et al. (2019) coded movement patterns as either standing, walking sideways, walking backwards, walking forwards, side stepping, jogging, sprinting, turning to change direction, or turning to stop (Spencer et al., 2019). Additionally, the area of the court in which the umpire was positioned was coded as either goal line, goal third side line, or centre third sideline (Figure 1). Intra-class correlation coefficients were calculated for the percentage of time spent performing each movement classification (1.00; 95% confidence interval: 0.99, 1.00) and the frequency of movements (0.99; 95% confidence interval: 0.97, 1.00), indicating *excellent* reliability (Koo & Li, 2016). The majority of time was spent standing (49%) or walking (28%), with 10% sprinting, 5% jogging, and 4% each for side stepping and turning (Table 1). Additionally, 65% of time was spent on the centre third side line, with 16% on the goal third side line, and 19% on the goal line. Umpires averaged 140 ± 24 sprints per match for a duration of 2.8 ± 0.3 s. The authors did not report how movement patterns differed between the three court areas. For example, it may be useful for technical development programmes to understand whether elite umpires move differently on the goal line to on the side line, or whether movement on the side line differs between the centre third and goal third (*e.g.* Do elite umpires sprint more on the goal third sideline than centre third sideline? Do elite umpires walk or sidestep more on the goal line?). Furthermore, it must be recognized that umpires are often stationary whilst the ball is in the co-umpire's area of control. Therefore, a separation of movement patterns in each half of the court may also be beneficial (*e.g.* How much of the 49% standing is due to play being in the other half of the court?).

Interestingly, Spencer et al. (2019) did separate their movement analysis according to quarters of the match (Spencer et al., 2019). As the match progressed, the average duration of low intensity movements generally increased. Compared to quarter one, umpires walked for longer sideways in quarter four (mean 1.36 ± 0.17 s *vs* 1.29 ± 0.16 s), forwards in quarters three and four (2.39 ± 1.35 s and 2.42 ± 1.40 s *vs* 2.36 ± 0.56 s), and backwards in quarter two (1.51 ± 0.35 s *vs* 1.39 ± 0.42 s). Similarly, mean standing duration was longer in quarter two (4.55 ± 0.88 s) than quarter one (4.10 ± 0.88 s) and longer in quarter four (4.54 ± 0.86 s) than quarter three (4.41 ± 0.55 s). Contrastingly, a lower proportion of time was spent side stepping in quarter four (3.62 ± 2.45%) than quarter one (4.47 ± 2.72%).

The reduction inside stepping and increase in walking and standing throughout the match may explain the decreases in both total distances travelled and heart rate discussed in previous sections of the present review. It seems likely that elite umpires make a technical adjustment as the match progresses, enabling them to remain stationary for longer and perhaps maintain an optimal viewing position from which to make accurate decisions. As speculated previously, this may be facilitated by an enhanced perceptual-cognitive anticipation of passages of play by the two teams on court. Future research is necessary to confirm or refute this proposition. A comparison of the results of Otago et al. (1994) and Spencer et al. (2019) demonstrates differences due either to the higher standard of umpiring in Spencer et al's more recent study or changes in umpiring technique since 1994 (Otago et al., 1994; Spencer et al., 2019). Although a similar proportion of time is spent sprinting (10% Spencer et al. *vs 12*% Otago et al.), jogging (5% *vs* 7%), and side stepping or changing direction (8% *vs* 5%), much more time is spent standing (49% *vs* 21%) at the expense of walking (28% *vs* 54%) in the more recent and higher playing standard investigation (Otago et al., 1994; Spencer et al., 2019). This again implies that higher standards of umpiring may be characterised by a reduction in unnecessary low intensity movement, with elite umpires simply transitioning from one optimal decision making position to another and remaining stationary in between.

DISCUSSION

The limited available literature (Otago et al., 1994; Spencer et al., 2019) report that on average elite netball umpires cover approximately 3850 m during a 60 min match (Table 1). Up to around 50% of the match is spent standing, with only around 25% of the match in higher intensity movements such as jogging, sprinting, side stepping, or changing direction. Work:rest ratios are typically approximately 1:3 during match play, with additional recovery in the intervals between quarters. This includes an average of 140 sprints for a mean duration of 2.8 s. Elite umpires spend around 10% of the match at greater than 92% peak heart rate, with the majority (approximately 55%) between 75 and 92% peak heart rate. Such information may be useful for umpires and strength and conditioning practitioners when designing training programmes or fitness testing procedures. It should be additionally considered that rule changes enabling a player to choose to play the ball before the sanction has been set, introduced in 2016 (International Netball Federation, 2015), may slightly reduce the average rest duration available to umpires.

The literature (Spencer et al., 2019) also report a reduction in distance travelled by elite umpires as the match progresses (Table 2). The accompanying decrease in heart rate suggests that this is not caused by physiological fatigue mechanisms but is a result of technical adjustments in the movement patterns utilised. Indeed, elite umpires tend to sidestep less and walk or stand more as the match progresses. No such reduction in intensity has been observed in netball players (Cormack et al., 2014), which again implies that the more stationary nature of umpires is not a reaction to a reduced match pace. It is worthy of note, however, that elite UK Netball Superleague umpires in the 2014 season made more observable decisions in the first quarter than the third or fourth quarter (Burnett, Bishop, Ashford, Williams, & Kinrade, 2017). It is not clear whether this reflects a reduction in playing intensity or an adjustment of the players to the officiating style of the umpires.

In order to aid the technical development of umpires, future research should conduct separate movement pattern analyses for each area of the court as discussed previously. It may be useful to understand whether elite umpires move differently on the goal line to on the side line, or whether movement on the side line differs between the goal third, centre third, and when play is in the co-umpire’s area of control. Highlighting the characteristics describing successful umpiring may be facilitated by a more detailed comparison of movement patterns between umpires of differing standards. Furthermore, no existing literature has attempted to relate umpire movement and positioning to decision making accuracy as in other sports (Hossner et al., 2019; Mallo et al., 2012). Once the optimal positioning and movement patterns have been determined, it may be beneficial to identify the perceptual-cognitive processes (*e.g.* gaze behaviours) used by elite umpires to make superior decisions regarding positioning and movement. Moore et al. (Moore, Harris, Sharpe, Vine, & Wilson, 2019) recently analysed decision making accuracy and gaze behaviours of elite and trainee rugby union referees while reviewing scrum scenarios, showing that gaze fixation locations were significant predictors of decision making accuracy. Such an analysis of netball umpires could be extended to assess decisions regarding movement and positioning.

Finally, no attempt has currently been made to relate activity profiles of netball umpires to appropriate fitness testing requirements or to validate existing fitness testing protocols for umpires. For example, Gasston and Simpson (2004) used an analysis of netball player movement during matches to design the Netball Specific Fitness Test, an incremental test involving forward, backward and sideways movement, jumping, lunging, turning, and choice reaction (Gasston & Simpson, 2004). The test was found to be representative of movement in netball matches and to distinguish between players of different standards. In officiating, Mallo et al. reported that fitness tests adopted by FIFA for international association football referees were poor predictors of match activity profiles (Mallo, Navarro, Aranda, & Helsen, 2009; Mallo, Navarro, García-Aranda, Gilis, & Helsen, 2007). However, referees with better heart rate recovery after an interval test were able to produce more intense exercise during matches without needing to spend so much time in high heart rate zones (Mallo et al., 2009). These findings provide a rationale for a similar analysis of netball umpire performance and fitness testing protocols, something absent from the current literature.

CONCLUSIONS

This review has outlined the existing literature relating to activity profiles in elite netball umpires. In particular, the physical (distance travelled), physiological (heart rate), and technical (movement classifications) characteristics of elite netball umpiring have been described. These characteristics may benefit umpires and strength and conditioning practitioners when designing training programmes for netball umpires. Additionally, gaps in the existing literature have been highlighted, including the relationship between visual perception and movement, and the application of umpire activity profiles to fitness testing requirements.

CONFLICTS OF INTEREST

Authors report no conflicts of interest.

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