Performance Analysis of High Performance Netball Umpires for Match-Play and Fitness Demands

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Abstract

Background: Athletes strive for optimal performance in sport, and this is no different for high performance netball umpires. Performance of referees/umpires in elite sport (i.e. soccer, rugby union, rugby league, field hockey and basketball) has been widely investigated to assess match-play demands, and in some cases fitness testing performance has been compared to match day performance measures, including speed, distance covered and physiological demands. To our knowledge, no data has been collected on Netball umpires over the past 20 years and findings within other high performance sports indicate that the current fitness testing utilized for high performance netball umpires may also not correlate to actual match day demands.

Purpose: The aim of this study was to assess the match-play physical, physiological and movement demands for three levels of elite umpires during 2012 New Zealand (NZ) netball season and to ascertain if the current Netball New Zealand (NNZ) fitness tests correlated to these match-play demands.

Methods: There were two stages of the data collection for this study, 1) match day observations and 2) the completion of the NNZ battery of fitness tests. A sample of convenience was recruited from the NNZ High Performance Netball Umpire Squads, and they were ranked from 1 to 22 (with 1 as the best) and categorised into three performance level; Group One (N = 9, ranking 1 - 9) Group Two (N = 6, ranking 10 - 15) and Group Three (N = 7, ranking 16 - 22). Catapult mini-max S4 Global Positioning System (Catapult Sports, Victoria, Australia) units and Polar Team^2 heart rate monitors (Polar Electro, Oy, Kempele, Finland) were worn by participating umpires (N = 22) for the duration of each match and each fitness test. All matches and fitness tests were filmed using a Canon LEGRIA HV40 video camera, and the footage was uploaded to Sportscode Elite Version 10 (Sportstec, NSW, Australia) for analysis. The fitness tests used were the current NNZ protocols for the Yo Yo Intermittent Recovery Level 1 Test, the anaerobic Octorepeater Test and the 5, 10, 20m Speed Test.

Results: Umpires travelled a distance of 3.84km, worked at an average intensity of 80% of Heart Rate peak and spent the most time (35%) in HR Zone 3 (75 – 85% of HRpeak). Work-rate (Player Load and Heart Rate), frequency and percentage of time performing work movements followed a trend of decreasing across the duration of a match for all umpires. Umpires spent 49% of a match standing, 23% of time working and 10% of time sprinting.

Group One umpires overall worked at higher intensities (HR and movement demands) than both Group Two and Three and also chose to use movements that orientated their bodies and heads more towards the ball.

Correlations were found between the Yo Yo fitness test distance and the percentage of time jogging during match-play (r = .51, p = .03), Mean HR in both the Yo Yo (r = .59, p =.01) and Octorepeater (r = .50, p = .03) was correlated with the percentage of time working during match-play. The frequency of turns in the Octorepeater correlated with the amount of turns during match play (r = .48, p = .05).

Conclusion: The correlations between the amount of jogging during match play and during the Yo Yo Test and the frequency of turning during match-play and the Octorepeater both suggest some validity of current testing protocols. However as all other correlations were poor the overall results indicate that the current fitness tests are not a valid indicator of match-performance though may be used as normative tests for base line fitness.

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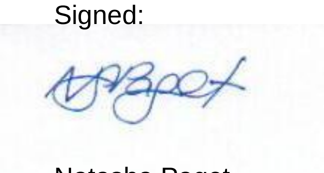
Attestation of Authorship

“I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.”

Signed:



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Thesis Outline and Structure

This thesis is presented in five chapters. Chapter One provides an introduction to match officiating and the sport of Netball, the thesis aim, purpose and research questions.

Chapter Two is a literature review based on time and motion analysis for match officials and netball players, including information on movement classification systems and GPS analysis.

Chapter Three explains the methodology procedures, including the experimental design, selection of participants, match day and fitness testing data collection procedures. It also explains the data and statistical analysis processes used within this thesis.

Chapter Four presents an analysis of the movement and physiological demands placed on elite umpires during match-play, highlighting any differences across different levels of umpiring. It also assesses the relationship between the current NNZ fitness testing protocols and the match-play demands, and the validity of the current testing protocols.

Finally Chapter Five provides a discussion based on the thesis findings, the overall summary and conclusion of the thesis, including practical applications, limitations to current research and opportunities for future research.

Chapter One: Introduction

Invasion ball sports require officiating from two or three umpires (also known as referees) in order to maintain fairness and order to the game or match. At grass root level these officials may be coaches, players or even parents helping out on a Saturday morning to ensure the game runs smoothly and organised. At an elite level the same reasoning for officials applies, however the stakes are much higher with money, sponsorship, championship titles and pride on the line.

Elite players have teams of coaches for skill, tactics and fitness, and in some cases so do the officials (Mascarenhas, Collins, & Mortimer, 2005). The increased level of skill and fitness by the players demand officials to keep up with the match-play, as well as ensuring they are always making the right decision at each moment within the game. An example of this need for 100% accuracy in decision making is the increased use of a television match official (TMO) in Rugby Union and Rugby League. The frequent use is to ensure the outcome of the match can be absolutely fair to both teams, i.e. a try is scored or not. First line umpires do however need to be able to keep up with the play, and make most decisions on the fly and be confident that they are making correct ones.

Invasion ball sports are officiated in different manners dependent on the specifics of the sport. Football, Rugby Union and League are all played on large fields which require longer periods of running and sprinting and have one main official on the field of play and two assistants, one on each side line. Court based invasion sports such as Basketball, Field Hockey and Netball have two officials who each cover half the court and therefore do not require such long periods of running or sprinting as most field based sports. The size of the playing field and number of officials will then affect the demands placed on the official and the fitness requirements.

The most extensively researched umpires are in football, with results showing that umpires are required to perform frequent high intensity repetitive sprints during a match (Casajus & Castagna, 2007; Krustrup et al., 2006; Mallo, Navarro, Garcia-Aranda, Gilis, & Helsen, 2007; Mallo, Navarro, Garcia-Aranda, & Helsen, 2009; Weston, Castagna, Helsen, & Impellizzeri, 2009), with overall distances covered during a match ranging from 10.2 – 11.5km (Mallo et al., 2007; Mallo et al., 2009; Weston et al., 2009). Research also indicates that the amount of running at high speeds is the best way to describe the performance of elite football umpires, although the actual percentage of time spent sprinting during a match is low ranging from 4.6 – 7.1%. Mean percentage of HRpeak for a football umpire is 86% (Mallo et al., 2009) and they spend approximately 27.4% - 31.7% of total time stationary during a match (Mallo et al., 2007; Mallo et al., 2009). In contrast during a Rugby Union match a referee will cover an average of 8.6km with only 1% time spent sprinting and 37% standing still (Martin, Smith, Tolfrey, & Jones, 2001). Rugby League refereeing is also considered highly intermittent, with time spent stationary at 41% of total game, average distance covered 6.7km (B. Kay & N. D. Gill, 2003), and a mean percentage of HRpeak of 84% (Kay & Gill, 2003a).

An international field hockey umpire covers less ground during a match with a mean of 6.7km and only 0.3% of time spent sprinting. Their mean HR was found to be 149bpm (Sunderland, Taylor, Pearce, & Spice, 2011). Elite Basketball umpires have a mean HR of150bpm during a game (Leicht, 2008) with no current research available for distances covered or movement pattern analysis. Lastly the only research on netball umpires available show the average distance covered during a match is 3.8km, with 21% of time was spent stationary and 12% spent sprinting (Otago, Riley, & Forrest, 1994).

These hugely different match-play demands therefore require suitable and valid fitness testing protocols to suit each sport. Assessment protocols for match official selection at the national and international level include not only split second decision making ability and knowledge of the rules, but the ability to keep up with the play and thereby pass an appropriate minimum level during fitness tests in order to prove match fitness. Sporting organisations stipulate fitness assessments for their players and officials however the fitness tests chosen are not always valid for the officials based on the differing nature of umpire match day demands to players. Umpire demands do not include jumping, impacts, dodging players and other offensive and defensive manoeuvres that are specific to players. However often they do require sprinting and quick change of directions (COD) in order to place oneself in the right place to make a decision.

More recently within some sports (football, rugby league, and rugby union) match day performance demands have been compared to their fitness testing protocols to determine if the specified test protocols agree with the demands placed on them during competition (Castagna, Abt, & D'Ottavio, 2002; Mallo et al., 2007; Mallo et al., 2009; Martin et al., 2001; McLellan, Lovell, & Gass, 2011; Weston et al., 2009; Weston, Castagna, Impellizzeri, Rampinini, & Abt, 2007). In some cases, no correlation existed between the fitness tests and match day performance for football (Mallo & Navarro, 2009; Mallo et al., 2007). Based on the low validity of the fitness assessments, the Federation Internationale de Football Association (FIFA) re-assed their battery of fitness tests and a study examining these new protocols observed relationships between the match day analysis and fitness testing results (Weston et al., 2009).

Within the sport of Netball, although some research exists for players, recently it has been noted that the limited research on elite players has made it hard to identify match demands and the physical characteristics required (Fox, Spittle, Otago, & Saunders, 2013).There is then an opportunity to investigate the demands placed on elite netball umpires and validity of their fitness tests based on the same rationale.

Netball is not only the most popular female chosen sport in NZ, but boasts one of the largest sporting participation numbers within Commonwealth countries, which includes Australia and the United Kingdom (Chandler, Pinder, Curran, & Gabbett, 2014; Steele & Chad, 1992). With such large international participation numbers, outcomes of such research would provide a basis to improve training and testing of netball umpires not only at the elite level, but also at community level.

The game of netball is a fast paced invasion ball sport held on a 30.5 x 15.25m court with one round ball, one goal post and hoop at each end and seven players on each side. Playing positions are split into defence and attack, with one centre position who may run the full length of the court except for the goal circle. Two positions are able to shoot goals (Goal Attack and Goal Shoot), whilst the opposing two defence aim to stop this (Goal Defence and Goal Keep). The final two positions are on the wing, with one attack (Wing Attack) and one defence (Wing Defence). (Figure 1)

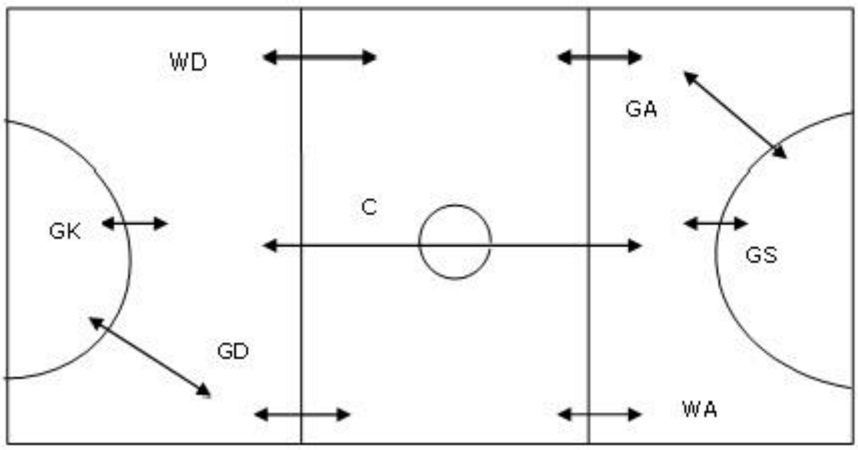

Figure 1, Netball Court and Playing Positions

Regional, national and international matches in NZ have three umpires assigned, with two officiating and one as a reserve umpire on standby in case of injury. Umpires take control of half the court, and one side line and base line (Figure 2) and are required to follow the play of the ball at all times.

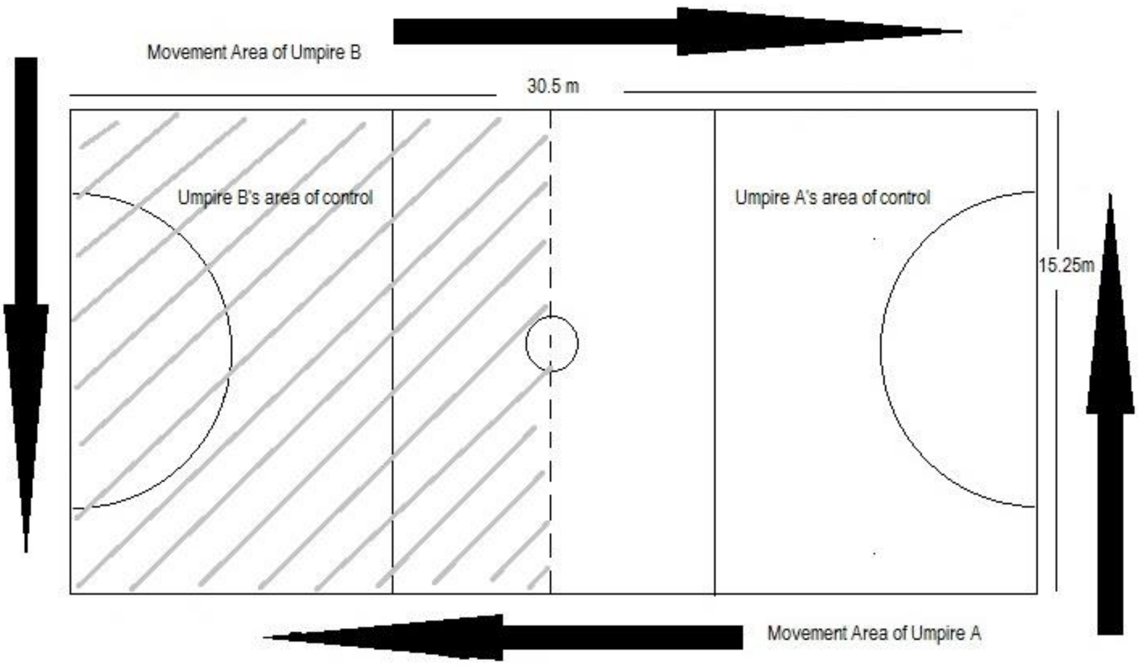

Figure 2, Umpire control area

Research has determined the physiological and movement demands placed on netball players (Davidson & Trewartha, 2008; Loughran & O'Donoghue, 1999; Maddock, 2003; O'Donoghue, Mayes, Edwards, & Garland, 2008; Woolford & Angrove, 1992) however only one published study has looked at these same demands for netball umpires (Otago et al., 1994). There also has been recent analysis on netball players providing suggestions for new fitness tests with greater validity for match-play demands (Farrow, Young, & Bruce, 2005; Gasston & Simpson, 2004).

For players, netball is considered a high intensity intermittent sport (Chandler et al., 2014; Davidson & Trewartha, 2008; Fox et al., 2013) and this also maybe the case for umpires based on the flow of the match. However the demands for a netball umpire may differentiate substantially from those for a netball player due to the type of movements and the location on the court they move in. The limited and dated research on netball umpire work rate's, intensity and movement analysis , indicates that in order for an analysis to be done on current fitness testing or training protocols, the demands that are placed on netball umpires during a match must first be determined..

It is also of note that the International Netball Federation has differing fitness assessments than the National Netball sporting body in NZ - NNZ. With all international level umpires required to pass the multi stage shuttle test, also known as the beep test (Ramsbottom, Brewer, & Williams, 1988) whereas NNZ requires their national and development umpires and players to perform the Yo Yo Intermittent Recovery Test Level 1.

Prior to the commencement of this 2012 study, no technological attire was worn officially by umpires to record physiological or movement data during a match. Today technology such as global positioning systems (GPS), accelerometers, heart rate transmitters, and advanced performance analysis hardware/ software makes it possible to provide a detailed picture of player and umpire movement and performance.

Indeed sports utilising advanced technologies to monitor and assess performance for their umpires include football, rugby union, rugby league, basketball and field hockey (Casajus & Castagna, 2007; Castagna et al., 2002; Castagna & D'Ottavio, 2001; Catterall, 1993; da Silva, Perez, & Fernandes, 2007; de Oliveira, Guerrero Santana, & de Barros Neto, 2008; B. Kay & N. Gill, 2003; Kay & Gill, 2004; Kraak, Malan, & Van den Berg, 2011; Krustrup & Bangsbo, 2001; Krustrup, Mohr, & Bangsbo, 2002; Leicht, 2004, 2008; Mallo et al., 2007; Mallo et al., 2009; Martin et al., 2001; O'Conner, 1994; Sunderland et al., 2011; Weston, Castagna, Impellizzeri, Rampinini, & Breivik, 2010; Weston, Drust, Atkinson, & Gregson, 2011). However, to our knowledge, no recent data on netball has been reported using such technology and doing so may provide a more detailed representation than previous estimations based on video analysis alone (Otago et al., 1994).

With the advances in technology and need for an analysis on netball umpires there is an opportunity for a new and innovative research design. The gap in research on netball umpires highlights the need for information on high performance netball umpire match-play demands because of the increasing performance of players at this elite level. As fitness testing is an integral part of high performance athlete selection and assessment, benchmark fitness levels must be accomplished in order to achieve at in elite competition and ensure that fitness ability does not encroach on decision making ability by umpires. It is therefore also relevant to ensure that the current fitness assessments utilised by NNZ are valid for assessing an umpire's fitness in order to officiate at high performance netball tournaments.

Thesis Aim:

The purpose of this thesis was to determine the physical, physiological and movement demands of elite umpires and the relationship between the current NNZ fitness tests for elite umpires and match demands.

This was achieved by addressing the gap in knowledge for netball umpires through three performance related research questions.

1. What are the movement patterns, physical and physiological demands of match day performance for high performance netball umpires?

2. Is there variance in the movement patterns, physical and physiological demands between higher and lower ranked umpires?

3. Does umpire performance in the NNZ specified fitness tests correlate with the movement, physical and physiological demands expressed during competition?

Chapter Two: Literature Review

Introduction

In order for elite netball matches to be officiated at the highest standard possible, and therefore have the fairest outcome, umpires must strive for optimal performance on match-days. Performance of umpires in ball sports can be analysed in similar ways to players, however modifications to many of the performance analysis tools are required due to no ‘on the ball’, defensive or attacking movements.

Important aspects of an umpire’s performance include movement patterns and physiological indices. To our knowledge, there is no data published on Netball umpires since 1994 (Otago et al., 1994); however more recent studies have analysed netball player movement and physiological demands during competition (Bruce, Farrow, Raynor, & May, 2009; Davidson & Trewartha, 2008; O'Donoghue et al., 2008). Recent research found a need for a netball specific fitness test due to the low validity of the previous protocols (Gasston & Simpson, 2004), this suggests and supports the need for a similar analysis of netball umpire performance and testing protocols.

Match Day Demands

To reach optimal performance an umpire’s performance must firstly be analysed in order to understand the movement patterns and physiological demands, and then critiqued to highlight where improvements need to be made. An analysis of match day demands is needed in order to confirm specific requirements of an umpire for the duration of a match. There are multiple components of performance that can be analysed, however this literature review will focus on movement patterns and physiological indices, including distance travelled (in order to determine fitness levels required), speed and intensity (heart rate and work to rest ratio).

Due to the minimal amount of research undertaken on activity or movement patterns within netball competition, this review has included netball research dating back to the early 1980’s. The methods and equipment used then differed to what we now have available for performance analysis, and therefore limited the scope of the earlier findings. The only research found that specifically investigated netball umpires’ was completed in 1994 in Australia by Otago et al. Therefore as similar concepts of performance analysis have been studied in other invasion ball sports, including football, rugby, basketball and field hockey, these have also been included in this review. The findings from these other sports are useful to aid the development of an appropriate analysis system for this study of netball umpires.

Distance and Speed

Distance travelled has previously been calculated by the use of video footage, electronic timing gates and more recently Global Positioning Systems (GPS) within matches for both players and umpires. Calculations include total distance travelled in a match and distance travelled per each discrete movement type. Otago et al. (1994) estimated distance travelled by netball umpires through an analysis of video footage and related this to the court dimensions. Only one match was analysed in this way using an A-grade umpire and she was found to travel a total of 3.85km in a 60-minute match (composed of 4 x 15 minute quarters). An A-grade umpire in Victoria, Australia is classified as the level between a club and an elite competition. A limitation when using estimation based on video is that it may lead to variability in distance results as the analyst has to guess each of the distances. These results may then be questionable or could be considered unreliable especially as no reliability test was completed within the study (O'Donoghue, 2007).

More recently netball players were shown to travel considerably different distances dependent on their playing position. It was noted that this was the first study to their knowledge that had reported total distance travelled by netball players during competition. A Centre travelled a total mean distance of 8 km during a match, whereas a Goal Keep or Goal Shoot only travelled a mean distance of 4.2 km (Davidson & Trewartha, 2008). Distance was calculated by using electronic timing gates to measure speed for each specific movement pattern in a separate session to the match play. Time spent on each movement type within the match was calculated, and then both of these measurements were used to predict distance based on the relationship; distance = speed x time. These movements included: Standing, Walking, Jogging, Running, Sprinting and Shuffling. Using a 15-minute section for each position intra-observer reliability was tested and was confirmed with a range that differed for a Goal Shoot from 0.3% for walking to 11.8% for running. Results found were valid for the positions that were investigated, however limitations can be identified and improvements made to ensure greater validity and reliability with this type of performance analysis in the future.

A limitation within the above study is that as these distances were calculated based on the relationship with another measurement rather than the actual measurement of the variable of interest, this could lead to reduced accuracy of the results, which is similar to estimating the distance results in the previous study for one umpire (Otago et al., 1994). As well there is a lack of research on elite netball players therefore little opportunity to compare these results to confirm accuracy. This more recent data could also however be relevant to the distances that umpires now to travel during a match. In order to confirm if this suggestion has some truth, an investigation needs to take place for high performance umpires in recent matches.

A more reliable way to calculate distance travelled is with the use of a GPS unit. The use of GPS to track a player’s movement, speed and distance has been used in training, testing and match play situations. Measures such as, maximum running speed, the number of sprints, total distance travelled and distance whilst sprinting are all useful when determining the performance of an individual. Two different brands of GPS have been commonly utilised to measure performance for both umpires and players, the SPI-Pro from GPSports, Australia (Coutts & Duffield, 2010; Duffield, Reid, Baker, & Spratford, 2010; Sunderland et al., 2011) and the Mini-max from Catapult, Australia (Dogramac, Watsford, & Murphy, 2011; Varley, Fairweather, & Aughey, 2012).

MacLeod, Morris, Nevill, & Sunderland (2009) found that the Spi Elite GPS provided high validity during actual matches when measuring distance and speed during field hockey. Umpires within this sport at an elite level were found to travel between 5.8 and 7.5 km in a match (70 minutes), with 9.3% of this a high speed (Sunderland et al., 2011).

Whereas international football umpires covered 10.2 km on average and assistant umpires 6.8 km within a 94-minute long match (Krustrup et al., 2002). An adjustment for this time to compare distance between football and field hockey would show football umpires travelling 7.8 km (umpire) and 5.2 km (assistant umpire) in 70-minute period. Field hockey averaged 6.7 km in a match, therefore the distance demands for hockey umpires fell between a football umpire and an assistant umpire (Sunderland et al., 2011). The findings may be limited however due to a small sample size of 10. These results are interesting when you then compare them to the only published distances travelled by a netball umpire. According to Otago et al. (1994) a netball umpire travels 3.85 km in a 60-minute match, which is approximately half the distance of a field hockey or football umpire travels within a match. These differences could be related to the field or court size, as for both football and field hockey the field size is much larger in comparison to the netball court. This may also mean any fitness testing techniques that have proven valid and reliable for these sports may not be appropriate for netball due to the smaller distances they are required to cover within a match. Again this presumption requires an investigation with regards to current netball umpire match demands and the fitness testing that they currently utilise.

The Spi Pro was also used to collect data on elite players in Rugby League using real time, which is where the data is sent live to a transmitter and straight to a computer with an analyst. The use of this system was found to be successful in calculating distance using real time (McLellan et al., 2011). MacLeod et al, (2009) also found that the Spi Elite GPS provided high validity during actual games when measuring distance and speed.

Based on literature up until 2010 it appeared there were acceptable levels of accuracy for peak speeds and overall distances for intermittent type high intensity sports, but the greater the intensity the less reliable the results were (Coutts & Duffield, 2010).

The accuracy and reliability of GPS units were investigated using a court-based specific study. A comparison of their results to a high-resolution motion analysis system of 100Hz found that both 1HZ GPS (Spi Elite, GPSports) and 5HZ GPS (Minimax, Catapult) units under reported distances and underestimated speed, and therefore this study suggested in confined spaces it was better to use a higher-resolution measuring device. They also found inter-unit reliability discrepancies, and it was suggested that the same unit is to be used on the same participant for repeated measures (Duffield et al., 2010). As this study was completed in 2010, results then may not apply to recent GPS units and the researchers noted that this technology is consistently being refined and improved.

Available on the market now are higher Hz GPS units like the 10Hz (10 samples per second) Catapult mini-max which was investigated for validity and reliability when measuring ‘instantaneous velocity during acceleration, deceleration and constant velocity while straight-line running' (Varley et al., 2012). Both 5Hz and 10Hz GPS units were compared against a tripod-mounted laser to test validity. As previous studies (Duffield et al., 2010) had questioned the validity and reliability of this equipment for use in team sports the newer 10Hz units were found to be 2 - 3 times more accurate at finding changes in velocity and 6 times more reliable, they were also considered reliable and accurate for straight-line running.

Low ecological validity was found in this study with regard to constant movement changes as only straight line running was analysed, therefore further study was suggested in this area. To our knowledge no research has examined the use of GPS units for netball umpires during high performance competition, however with the results of these recent studies it would seem that the use of a GPS unit to measure distance and speed could be a valid and reliable tool.

Player Load ™ and Estimated Equivalent Distance are two variables that are specific to the Catapult Minimax S4 GPS unit (Catapult, Victoria, Australia) that was utilised for indoor mode data collection.

Player Load™

The use of a triaxial accelerometer has been proven useful for determining the physical demands (rate of change in acceleration in three planes of movement, up/down, side/side and forward/backward) of match play in basketball for players (Montgomery, Pyne, & Minihan, 2010). Recent GPS units such as the minimaxS4 (Catapult, Australia) not only link to satellites but also include a triaxial accelerometer of 100Hz, as well as a gyroscope (100Hz) and heart rate compatibility with devices such as Polar heart rate straps (Polar Electro, Oy, Kempele Finland). In all these studies mentioned previously research with GPS units have taken place outside using satellite coverage, however for netball umpires the majority of elite matches are now held indoors. This presents some challenges for tracking distance indoors with a GPS unit, however Catapult (Australia) have recently developed an indoor mode, which uses the triaxial accelerometer to estimate distance based on player demands (also known as player load).

Player Load ™ is used as a measure of exertion or work-rate, and is useful to identify if netball umpires work-rate is consistent, decreases or increases across a match and any differences between umpire levels. Accumulated Player Load is the total workload across a period of time in comparison to Player Load which is an instantaneous effort. Differences in work-rate can identify if umpires are required to work at the same intensity for a 60 min match, or if there is a drop off. Player Load was developed by Australian Institute of Sport (AIS) for Rugby Union to measure effort (Catapult, Victoria, Australia

), and has been used in research over the past few years as gauge of effort in Australian Rules Football (Gastin, McLean, Spittle, & Breed, 2013; Weston, Siegler, Bahnert, McBrien, & Lovell, 2014; Young, Hepner, & Robbins, 2012).

Estimated Equivalent Distance

GPS units cannot triangulate with satellites if there is a barrier in the way, such as a ceiling when you are indoors so the Catapult GPS system estimates an equivalent distance based on player load. Estimated Equivalent Distance (EED) is an approximation of distance covered by using Player Load™. It relates to the distance an athlete would cover if jogging to reach the accumulated Player Load™. This method therefore is useful when assessing netball umpire distances covered for indoor matches.

A differing approach of using a GPS unit was to determine movement patterns based on calculated speeds. In a study on field hockey umpires, 1Hz (Spi Pro, GPSports) GPS units were used to calculate speed and distance, which they then related to movement categories. Standing and walking 0 – 4 km/hr, jogging 4 – 7 km/hr, slow-speed running 7 – 11 km/hr, moderate speed running 11 – 15.5 km/hr, fast speed running 15.5 – 20 km/hr and sprinting > 20 km/hr (Sunderland et al., 2011). These movement categories were then related to duration at intensity levels, which meant that when more time was spent sprinting, umpires were considered to spend more time at a high intensity pace.

Intensity

Research has shown that intensity levels within a match have been assessed or monitored in two different ways. With the use of Heart Rate monitors, HR can be monitored and include information including maximum, mean and minimum heart rate, as well as calculating the amount of time spent in different heart rate zones. Movement patterns can also monitor or assess intensity by measuring the frequency and duration spent in high intensity movements such as sprinting and jogging and comparing these to lower intensity or rest/recovery movements such as standing still or walking. By combining the two types of intensity analysis a greater picture of match day demands can be portrayed.

Heart Rate

Otago et al. (1994) recruited three A-grade umpires for data collection and they analysed five matches for the first umpire, nine matches for the second and ten matches for the third umpire. The third umpire's tenth match was also a higher level of competition than the previous matches, but still not considered elite level. Heart rate data was collected for all matches. Maximal Heart Rate (MHR) was calculated for each of the three umpires after they performed a maximal fitness test and these MHR's were then used to calculate individual heart rate zones. Four zones were used: Zone 1: >92% MHR (Aerobic and Anaerobic Endurance), Zone 2: 85 – 92% MHR (Anaerobic Threshold), Zone 3: 75 – 85% MHR (Aerobic Endurance) and Zone 4: <75% MHR (recovery and regeneration). These zones were used to identify how much percentage of time was spent in each intensity level, which corresponded to the use of specific energy systems (aerobic and anaerobic). The results from this information gathered was then used to identify the type of training that was required to meet the demands of these umpires on match days. This information is also useful to determine an appropriate testing battery based on the energy systems that are utilized. The percentage of time spent in different heart rate zones differed per game, depending on match difficulty. For example if the match was played between two teams who were at the top of the scoreboard the match would be considered more difficult, or if the match was played between a team from the top of the scoreboard and one from the bottom then it would be considered mismatched.

A difference in intensity results between each quarter within the match also was affected if for example the teams were mismatched. It would mean that one team would have a greater percentage of time with the ball in their attacking half, and therefore one umpire's work rate would be higher than the other for that particular quarter. A higher work rate would include more sprinting, running and shuffling in comparison to the rest-recovery movements of jogging, walking and standing. These results would then infer that not only the umpires match performance needs to be considered, but also the match outcomes including statistics such as final score and percentage of ball possession. The use of the multi stage fitness test (Ramsbottom et al., 1988) to find maximal heart rate has also been used in other sports such as field hockey to calculate individual heart rate zones (Sunderland et al., 2011).

Aside from the singular netball umpire study, basketball is the most relevant sport to netball where umpires have been investigated. The high level of relevance is due to the similar court dimensions, similar number of players on court (basketball; n=5, netball; n=7), teams pass a round ball by hand and the aim of the match is to score the most goals through a net. Two umpires are also used for each match. Basketball umpires have been shown to have significant stress on the cardiovascular system during competition (Leicht, 2004) and more recently it was found that international competition resulted in high exercise intensities for umpires. These intensities were based on the ACSM exercise intensity categories, very hard (>90% HRM), hard (70— 89% HRM), moderate (55—69% HRM), and light (35—54% HRM) and the proportion of time spent per quarter in the higher intensity zones were as follows, high (59%), hard (18%) and moderate (20%) (Leicht, 2008). It is worth noting that in comparison to the netball umpire heart rate zones, three of their zones fall within the very hard and hard intensity categories for the basketball study above. Therefore the results from the netball umpire study may to suggest that they performed at high exercise intensities. As per netball, these researchers also pointed out that there was minimal research on basketball umpires during match play (Leicht, 2004) and it is suggested that further research would assist in maximizing performance of umpires (Leicht, 2008).

Table 1, Heart Rate Zones used in Performance Analysis studies

Study	Sport	HR Zones Used
(Mallo et al., 2009)	Football Referees	1; <65%, 2; 66-75%, 3; 76-85%, 4; 86-95%, 5; >95%
(Weston et al., 2009)	Football Referees	1; <60%, 2; 60-75%, 3; 76-85%, 4; 86-93%, 5; >93%
(Otago et al., 1994)	Netball Umpires	1; <75%, 2; 75-85%, 3; 85-92%, 4; >92%
(Kraak et al., 2011)	Rugby Union Referees	1; <74%, 2; 75-84%, 3; 85-95%, 4; >95%
(Woolford & Angrove, 1992)	Netball Players	1; <75%, 2: 75-85%, 3; 85-95%, 4; >95%
(McLellan et al., 2011)	Rugby League Players	1; <45%, 2; 45.1-65%, 3; 65.1-80%, 4; 80.1-87.5, 5;87.6-95%, 6; >95.1%
(Leicht, 2008)	Basketball Umpires	1; 35-54%, 2; 55-69%, 3; 70-89%, 4; >90%

Movement pattern types

Another way of categorizing intensities during match play was to use movement patterns. By allocating certain movement types to work and rest/ recovery, the work to rest ratio could be calculated.

Loughran and O'Donoghue (1999) ran a study that's purpose was to identify work rate for club netball players using movement patterns. They discovered a higher intensity of play overall but had some similar results to Otago (1983) with regard to positional work to rest ratio's. Davidson and Trewartha (2008) classified their movement types into either rest-recovery or work.

Rest-Recovery: Standing, Walking and Jogging.

Work: Running, Sprinting and Shuffling.

Their results differed from Loughran and O'Donoghue (1999) as they found that players spent a greater amount of time in low intensity activity compared to high intensity activity. There were some limitations to this study however with the work to rest ratio's calculated based on game time only, and therefore no consideration of the breaks between each quarter and any injury time which would be considered as recovery. This then could alter the work to rest ratio again, with more time spent in rest type movements.

Within Rugby Union umpires were investigated for their movement patterns, heart rate and work to rest ratios (Kraak et al., 2011). Reliability for this study was considered excellent to good, with all results falling between r= 0.92 and r= 0.98. For higher performing matches, greater workloads such as jogging and sprinting were performed, however more time was spent with a lower intensity heart rate.

This information means that by combining the two types of intensity methods, we can then view overall umpire demands as well as individual umpire performance. If umpires regularly spend the majority of time on higher intensity movement patterns but their heart rate is more frequently in the lower heart rate zones, this could show us that umpires may have a high level of aerobic fitness.

Movement Pattern Analysis

Movement Pattern data collection has been completed with the use of time-motion studies and analysed with notational analysis. Data can be collected in real time with the use of pen and paper or video linked straight to a computer with a coding software, or by video or audio recordings for translation and classification later. Over the years the collection and analysis of this type of data has moved away from time consuming pen and paper, to video and software programmes specifically for coding movement patterns.

Three software programmes commonly used for performance analysis are:

> *Sportscode Elite (Sportstec, NSW, Australia).*
>
> Sportscode has been used in netball player analysis (Davidson & Trewartha, 2008). The time-motion analysis coded six different movements and test-retest results were considered reliable. Intra-observer reliability was confirmed with a difference ranging between, 0.3% and 11.8% for each movement using one period analysed by two different analysists.
>
> *Observer (Noldus Information Technology, The Netherlands).*
>
> This software programme was used with Bloomfields Classification System (Bloomfield, Polman, & O'Donoghue, 2004).
>
> *Focus X2 (Elite Sports Analysis, United Kingdom).*
>
> This software was utilised by Gasston et al (2004) to analyse netball player movement patterns in order to design a new fitness test.

Movement pattern and event coding has been considered reliable where there is a percentage of errors less than 5% (Jenkins, Morgan, & O'Donoghue, 2007; O'Donoghue et al., 2008).

Otago et al, (1994) found that the majority of a netball umpires' time was spent standing (21%) and walking (54%) during the match. The more intense movements including sprinting (12%) and jogging (8%) were not as frequently used. However these results were considered misleading in the discussion section in the research paper, as the average distances completed by each movement as well as the frequency of each movement indicated a different picture. On average each sprint was 10.7m long and a jog was 6.95m, whereas walking was only 5.5m and although the frequency of walking and standing was high, it was interspersed with sprinting and jogging which had a frequency of 106 and 87 respectively (Otago et al., 1994). Although the frequency of high intensity movements was less than the lower intensity movements of walking and standing still, more ground was covered overall within a match at these higher intensity levels.

Loughran and O'Donoghue (1999) used a different technique than the commonly adopted video, and used audio recordings of each match for analysis of movement patterns. Results showed a frequent change of activity. The main limitation of this study was that different observers were used to verbally record for different players, which was then in put into a computer. This could increase the variability of the results as different observers view activities/ movements slightly different. They did however account for the reliability by using a single participant and had two analysts record this participant's movement. Error ranged from 0.5% for a stationary activity through to 6.9% for running. This reliability test was similar to one performed in an earlier study by Steele and Chad (1991) when analyzing netball players movement patterns.

The activity and movement patterns for the study by Davidson and Trewartha (2008) were analysed using the computer programme Sportscode (Elite 6.5.2, Sportstech, NSW, Australia) and were based on movement classifications from previous research (Steele & Chad, 1992). Their results showed changes in player activity every 4.1 seconds. This intermittent movement type for players could mean that umpires may also be required to perform frequent movement changes during a match, which corresponded to the earlier findings of Otago et al (1994).

The analysis of netball umpires had an analyst pause the tape in between each new type of movement with both the type and time spent on that movement recorded, however frequently the analyst needed to rewind and time the movement again to confirm the time. The movement classifications used was similar to those used in player analysis, with the exception of changing direction. Movement classifications were: standing, walking, jogging, sprinting, side stepping, changing direction (Otago et al., 1994). A limitation of this type of analysis was that by pausing and starting for each movement, the analyst may not always pause at the same stage for each type of movement, which could lead to incorrect percentage of time spent on each type of movement recorded. No reliability test was performed for this analysis which limited its findings as it is important to confirm if the results are accurate and that if the same analysis technique was to be used again the same result would be given.

Other limitations with the use of video to collect data can include the use of one camera to focus on two players, therefore some data could not collected if a player went out of the range of the camera (Davidson & Trewartha, 2008). The use of TV coverage to track players during match play, as not all players could be tracked for an entire game (Otago, 1983).

As there is more recent literature on netball players, it is useful to review their movement patterns. Performance indicators for netball players are considered as success in goal shooting, passing, intercepts and centre pass (Bruce et al., 2009; Jenkins et al., 2007; O'Donoghue et al., 2008). Although these performance indicators differ from what would be considered as an umpire's performance indicators, as the court is the same it could be presumed that most movement types and intensity levels of match play may be more relevant than literature on sports which have greater field sizes and require greater distances to cover.

Video analysis has also been recently used to determine the relationship between match performance and physical testing in football (Mallo et al., 2007), and the validity of this type of analysis was confirmed high after a pilot study including both inter and intra-observer reliability.

In order to analyse video footage, a classification or coding system must be developed and used. One of the most predominant movement classification systems used for analysing sports was the Bloomfield Movement Classification system (BMC). Bloomfield, Polman & O'Donoghue (2004) designed the method to analyse movement patterns with more detail on motions, intensities, directions and events. This classification system was based on performance observations of football, field hockey, rugby union, rugby league, basketball and netball, and was shown to have the greatest reliability with football. It is a complex coding system, with 29 different motions to record, and two different types of modifiers to add to each motion such as directions and intensity. Due to the huge amount of detail required, it took a large amount of time to code even small amounts of footage (Bloomfield et al., 2004). Reliability of this classification system was shown to be a good to very high level of agreement using kappa values for both inter and intra observer (0.64 and 0.78, 0.79 and 0.92 respectively).

A modified version was applied to netball specifically (Hale & O'Donoghue, 2007), with only 12 movement types and 18 different directions of movement. Reliability was assessed with a good strength of agreement for movement type (k=0.63) and a moderate strength of agreement for direction of movement (k=0.44). Turning during movement was considered unreliable and not analysed during this study.

A further modification of the Bloomfield Movement Classification system (BMC) was used to investigate agility demands and injury risk in sport (Robinson & O'Donoghue, 2008). Five key events were decided upon:

a. event type
b. direction of movement before the event
c. direction of movement after the event
d. aspect change of any turn during the event
e. angle of any turn during the event.

Movements were then put into nine categories, smooth turn, sharp path change, linear turn, disjointed path change, braking, acceleration from stationary, jump take off, jump landing and on the spot turn. This modification was also made to make a more concise and user-friendly classification system.

When testing for reliability, footage should be analysed twice with one month apart, to lessen the possibility of retention of knowledge of the content of footage (Duthie, Pyne, & Hooper, 2003).

Overall, O'Donoghue (2007) recommended with any study on performance analysis, when training new observers that you should undertake an intra-observer reliability study and if reliability is poor use a simpler categorical version of the classification system.

Fitness Testing

A recommendation was made as early as 1993 to assess fitness levels of umpires, after research found that top-level football umpires had high physiological demands placed on them during match play. It was recognized that officials needed to be able meet these demands and that appropriate training and testing then needed to be undertaken to assist in improving performance (Catterall, 1993).

The Yo Yo Intermittent Recovery Test (Yo Yo) is currently utilised by NNZ as a benchmark for their high performance umpires, and has also been used as a fitness test for elite athletes in various other sports (Bangsbo, Laia, & Krustrup, 2008; Krustrup et al., 2003; Krustrup et al., 2006). It was originally designed for soccer players and its aim is to evaluate how well an individual can perform intense exercise repeatedly (Bangsbo et al., 2008).

The Yo Yo has been investigated with regards to its reliability and validity especially in soccer players, and on a lesser scale soccer umpires. The procedure consisted of running 2x 20m shuttles, with a 10sec recovery period. A review article by Bangsbo et al, (2008) on the Yo Yo test considered the test to have high reliability (see table 2).

Table 2. Reliability of Yo Yo Intermittent Recovery Test Level 1.

Study	**No. of Participants**	**Timeline**	**Coefficient of Variation (CV)**	**Correlation Coefficient (*r*)**
(Krustrup et al., 2003)	13	within a week	4.9%	
(Thomas, Dawson, & Goodman, 2006)	16	3 – 7 days	8.7%	0.95
(Krustrup et al., 2006)	28	1 week	8.1%	0.93

There is a significant correlation between the Yo Yo and players intensities during a football match (Bangsbo et al., 2008; Krustrup et al., 2003) as well as for football umpires. It is also considered to have high sensitivity for the use with athletes who partake in intermittent type sports such as football, and is valid when comparing with match day performance in football (Bangsbo et al., 2008) due to a great amount of high intensity running.

However the validity for netball, and in particular netball umpires may be questionable due to the size of their courts. As the court dimensions are much smaller than a football playing field, there could be differences in the distance to run as mentioned previously, and therefore heart rate intensities including both work and recovery periods for umpires to keep up with the game flow.

Gasston and Simpson (2004) designed a netball specific fitness test (NSFT), which replicated more efficiently the intermittent nature of netball in comparison to the original multi-stage fitness test (Ramsbottom et al., 1988) that had been used prior. The NSFT was designed based on the physiological and movement parameters as defined by a performance analysis on netball players using Focus X2 software (Elite Sports Analysis, United Kingdom). This performance analysis included the use of a modified movement pattern analysis based on Bloomfields Movement Classification (Bloomfield et al., 2004) which had not been applied to netball before. The researchers also noted that they had found limited research that addressed game performance and the use of this information to inform the testing and training protocols.

More recently within some invasion ball sports (rugby league, rugby union, football, field hockey and basketball) match day performance demands (distance travelled, speed, intensity levels and movement pattern types) have been compared to their fitness testing batteries to determine if the specified test demands and results actually correlate with the demands placed on them during competition (Castagna et al., 2002; Catterall, 1993; Kay & Gill, 2004; Kraak et al., 2011; Leicht, 2008; Mallo et al., 2007; Mallo et al., 2009; Martin et al., 2001; Mascarenhas et al., 2005; McLellan et al., 2011; Sunderland et al., 2011; Weston et al., 2009; Weston et al., 2007). Early findings showed no correlation between the fitness tests and match day performance for both football and field hockey (Mallo et al., 2007; Mallo et al., 2009; Sunderland et al., 2011) (Table 3).

Table 3. Review of match play and fitness test correlation studies

Study	Sport	Number of athletes/ matches	Fitness Tests	Correlation with Match Play measures
Relationship between fitness tests and match performance (Castagna et al., 2002)	Football referees	22 referees, 1 - 3 matches per referee – Serie A and B Italian Championships	50m, 200m and 12 min run test	Moderate correlation with 12 min run test and total match distance (r=0.71)
Activity profile in relation to fitness test performance (Mallo et al., 2007)	Football referees	11 referees, 12 under 17 world cup matches	Two 50m and 200m sprints, followed by 12 min run	No correlation with match activities
Activity profile in relation to fitness test performance and match standard (Mallo et al., 2009)	Football referees	11 referees during FIFA confederations cup	6x 40m sprint test and interval test	New tests poor predictors of match activities
Relationship between field test measures and physical measures (Weston et al., 2009)	Football referees	17 referees, 5 matches per referee – FA premier	6x 40m sprint test and interval test	Very large correlations fitness test results and match play distance, high intensity running and sprinting distance.
Relationship between fitness test and game behaviors (Smart, Hopkins, Kenneth, & Gill, 2011)	Rugby Union players	510 players, 296 games over 2 years	Sprint times 10m 20, 30m, body comp, strength and power, repeated sprint ability	Low correlations
Activity profile and physiological demands of top-class soccer assistant referees (Krustrup et al., 2002)	Football referees	15 assistant referees in 22 competitive matches	3x 30m sprint, treadmill test	Strong correlation with repeated sprints and amount of high intensity running in a game (r=.80)

Within a study on field hockey it was found that there was no decrease in performance between halves, which infers a high level of fitness for these umpires at this level. In this particular case a multi-stage fitness (Ramsbottom et al., 1988) test was used to assess umpires aerobic fitness and results of this study found that this test did not correlate with actual match day performance. Therefore perhaps an anaerobic fitness test would be more appropriate. In this instance a recommendation was made for testing and training procedures to be updated to reflect the specific roles of hockey umpires (Sunderland et al., 2011).

Over two different studies Mallo et al. (2007; 2009) compared the relationship of two different testing batteries with match play in football and found that they were both poor predictors of actual match performance. As these were the first investigations that have taken place within football of this type, it could infer that similar findings may occur in netball and that it is important to confirm whether the current fitness tests for high performance netball umpires are appropriate and valid. As Federation Internationale de Football Association (FIFA) regularly evaluate the fitness of their game officials (Mallo et al., 2007) it would seem important to be utilizing a fitness test that was relevant to actual match performance by the umpires.

After FIFA designed new tests based on the above studies, research was undertaken to monitor a football umpires match related physical capacity by video analysis and heart rate and relate these to the new tests. In this case there was some correlation between the tests and competition performance, however it was noted that further consideration was required to improve validity (Weston et al., 2009).

These findings within other high performance sports may then mean that the current fitness testing utilized for high performance netball umpires may also not correlate to actual match day demands. Therefore by analysing match day performance these results may inform us whether the current fitness tests do correlate, or whether a new fitness test should be designed to improve validity.

Conclusion

There is a wide array of investigation that has taken place with regard to match day demands and correlation to fitness testing for both players and umpires within ball sports. Although umpire performance has been analysed extensively in football (Castagna et al., 2002; Helsen & Bultynck, 2004; Krustrup & Bangsbo, 2001; Mallo et al., 2007; Weston et al., 2009), and on a lesser scale in field hockey, basketball, rugby league and rugby union (Kay & Gill, 2004; Leicht, 2004; Sunderland et al., 2011) and compared to their testing and training protocols, to date this has not been investigated in NZ for the sport of Netball. As NZ is considered one of the top countries in the world at this sport ("IFNA: Current World Rankings," 2012), it is important to continually strive for optimal performance for both players and umpires.

Based on the limitations that have been identified throughout this literature review, there is benefit in a study that considers how to calculate distance, record umpire movement and analyse the video footage reliably. Thereby focusing on improving these aspects and would therefore increase reliability and validity for further investigation. These would include one camera to be focused on one umpire per match, the use of 10Hz GPS units, which are considered the most accurate and reliable tool to calculate speed and distance travelled, and the use of a computer coding software that has been proven reliable to analyse movement patterns.

Heart rate data has also been proven as useful along with movement pattern analysis for determining match day intensities and demands. A study which included GPS units which are compatible with heart rate, can be utilised indoors or outdoors plus video footage of movement patterns would also portray a much more thorough picture of the demands placed on an umpire during elite competition.

Therefore in conclusion there clearly is a need for a thorough performance analysis to be conducted on high performance netball umpires for both movement and energy expenditure demands. Thereafter an analysis of specific performance demands for each level of competition and the key levels of difference can then inform fitness testing.

Chapter Three: Methods

This chapter details the methodology and data analysis for the overall study, including data collection procedures from match-day and fitness testing.

1. Experimental Approach to the Problem

In order to answer the three research questions, this study needed to take place in two stages. Firstly match-play observations and secondly completion of the NNZ battery of fitness tests for high performance umpires.

Match-play Observations

A descriptive study was undertaken to determine the physiological, physical and movement demands placed on High Performance Netball Umpires during match-play. Physical and physiological measures were determined from Indoor-mode Global Positioning System (GPS) and Heart Rate (HR) monitors and movement measures were determined from video footage. Umpires were analysed at two levels 1) as a whole group and 2) as part of their High Performance Umpire squad to produce descriptive data on work-rate (Player Load™), distance travelled (estimated equivalent distance), HR and movement variables (frequency, mean time and percentage of total time). This analysis provides outcomes to two of the three original research questions:

1. What are the movement patterns, physical and physiological demands of match day performance for high performance netball umpires?

2. Is there variance in the movement patterns, physical and physiological demands between higher and lower ranked umpires?

Fitness Testing

Match-play physical (GPS), physiological (HR) and movement measures were then correlated with pre and post season fitness test results (distance and time), physical (GPS), physiological (HR) and movement (frequency, mean time and percentage of time) measures to determine if relationships existed between the following fitness test and match-play variables.

Match-play:

Mean HR and percentage of HRpeak

Percentage of Time and Mean Time performing Work movements

Fitness Test:

Results

Mean HR

Percentage of Time and Mean Time performing Work movements

This analysis provides an outcome to the third research question:

3) Does umpire performance in the NNZ specified fitness tests correlate with the movement, physical and physiological demands expressed during competition?

2. Participants

A sample of convenience was recruited from the NNZ High Performance Netball Umpire Squads who officiated at a high level tournament based in NZ over the duration of one season (April – October 2012).

The umpires were categorised by performance level:

Group One, ANZC Squad, N = 9 (male n = 1, female n = 8) were defined as umpires who were part of the ANZC squad officiating in the Australia New Zealand Championships (ANZC), a trans-Tasman competition that took place during April – July 2012. The data collection included only matches played in NZ and NZ umpires.

Group Two, National A Squad, N = 6 (male n = 1, female n = 5) were defined as umpires in the National A squad officiating in the Lion Foundation Netball Championships (LFNC); twelve regional teams from NZ compete in this championship. Based on the previous year's ranking (2011), the top six teams are in Division one and the bottom six teams are in Division two.

Group Three, National Development Squad, N = 7 (male n = 3, female n = 4) were defined as umpires who are part of the National Development Squad officiating in both the LFNC and NZ age group championships (Under 17, Under 19 and Under 21).

As well as the defined grouping according to umpire level, umpires were also ranked from 1 through to 22 by NNZ based on their performance in the 2012 season, with 1 the highest. Group One consisted of ranking 1 – 9, Group Two consisted of ranking's 10 – 15, and Group Three consisted of rankings 16 – 22. These umpire ranking values were used to measure the relationship between umpire level and fitness test results.

Match-play Observations:

A total of 22 umpires (male n = 5, female n =17), participated in the match day observations after providing informed written consent to NNZ to take part in the research (March 2012).

Fitness Testing:

Twelve umpires (male; n = 4, female; n = 8) were present for the pre-season testing and twenty umpires (male; n = 5, female; n = 15) were present for the post-season testing (see table 4).

Table 4, Number of participant who took part in Pre and Post-Season Fitness Testing

Group	**Pre-season**	**Post-season**
ANZC Squad	*	7*
National A Squad	5*	6
National Development Squad	7	7
Total Group	12	20

**Some participants were unavailable for the 2012 fitness testing*

3. Data Collection

3.1 Equipment

Catapult mini-max S4 GPS unit

During each match and fitness test umpires wore a Catapult mini-max S4 GPS unit (Catapult Sports, Victoria, Australia) measuring 88x50x19mm and weighing 67g. This was chosen due to it being the smallest and lightest of its kind available in the current market (Catapult Sports, Victoria, Australia) so having minimal impact on umpire performance.

The indoor mode on the GPS units was utilised for all data collection. Using the GPS units in this mode meant that satellite coverage was not required and variables were calculated using the accelerometer (3D, 100Hz), gyroscope (3D, 100Hz) and magnetometer (3D, 30Hz) (Catapult Sports, Victoria, Australia).

A lightweight mini-max undergarment was worn under outerwear clothing and and the GPS unit was put in the pouch on the back (see Figure 3). The GPS unit was positioned just above and centered between the shoulder blades.

Figure 3. Catapult Mini-max vest and GPS unit (rear view).

Heart Rate Transmitter

During each match a soft Polar Team[2] Heart Rate strap was worn under all clothing and positioned next to the skin just below the sternum, with a Polar Team[2] HR transmitter clipped on the front. The Polar Team[2] Heart Rate transmitter coordinates with the Catapult GPS unit and provided ECG accurate HR measures (Polar Electro Oy, Kempele, Finland). HR data was recorded by the GPS unit, captured in real-time and analysed post-match using the Catapult Sprint Software.

Video Footage

Each match and fitness test was recorded using a Canon LEGRIA HV40 video camera. Video footage was uploaded to Sportscode Elite Version 10 (Sportstec, NSW, Australia).

3.2 Match-play Observations

A time and motion analysis was undertaken on the NNZ High Performance Netball Squads during the 2012 New Zealand Netball season. Data was collected from three High Performance level tournaments located in New Zealand. The ANZ Championships (April – July 2012, Christchurch, Wellington, Tauranga, Rotorua, Hamilton and Auckland), the Lion Foundation National Championships (3-5 October 2012, Baypark Arena, Tauranga) and the New Zealand Age Group, U19 and U21 Tournament (2-4 July 2012, Trusts Stadium, Auckland). All matches were indoor and at International level stadiums.

3.3 Match-play Procedures

Group One Umpires

No familiarisation with equipment was possible due to time limitations. GPS and HR equipment were given to umpires approximately 30-40 minutes prior to the start of the match due to accessibility. The substitute umpire underwent training and was in charge of ensuring the GPS unit was turned on as close to the start of the match as possible and turned off straight after the game. The substitute umpire was also required to check the HR strap was in position and transmitting a signal by using a Polar HR FT1 (Polar Electro Oy, Kempele, Finland) watch to receive the HR signal and show beats per minute (bpm). All umpires used the same GPS unit for each match.

Group Two and Three Umpires

The catapult vest and HR strap were given to the umpires at the beginning of the tournament and collected at the end of the tournament. The GPS units were turned on and put in the pouch in the vest, and the HR transmitters clipped onto the HR strap as close to the start of the game as possible (<5 min to match start time), HR signal was also checked at this time as per Group One umpires. GPS units and HR transmitters were recovered after each game, turned off and charged if necessary. All umpires used the same GPS unit for each match.

Video Analysis

Each match was filmed with one camera focussed per umpire for the duration of each match. Location was dependent on space available at each match and specified by the tournament organisers, as media and team camera’s had first option. The camera recorded all umpire movements for the duration of a match. In most circumstances cameras were positioned in an elevated area along the baseline (Figure 4). There was minimal movement of each camera once recording had begun to ensure higher quality video footage.

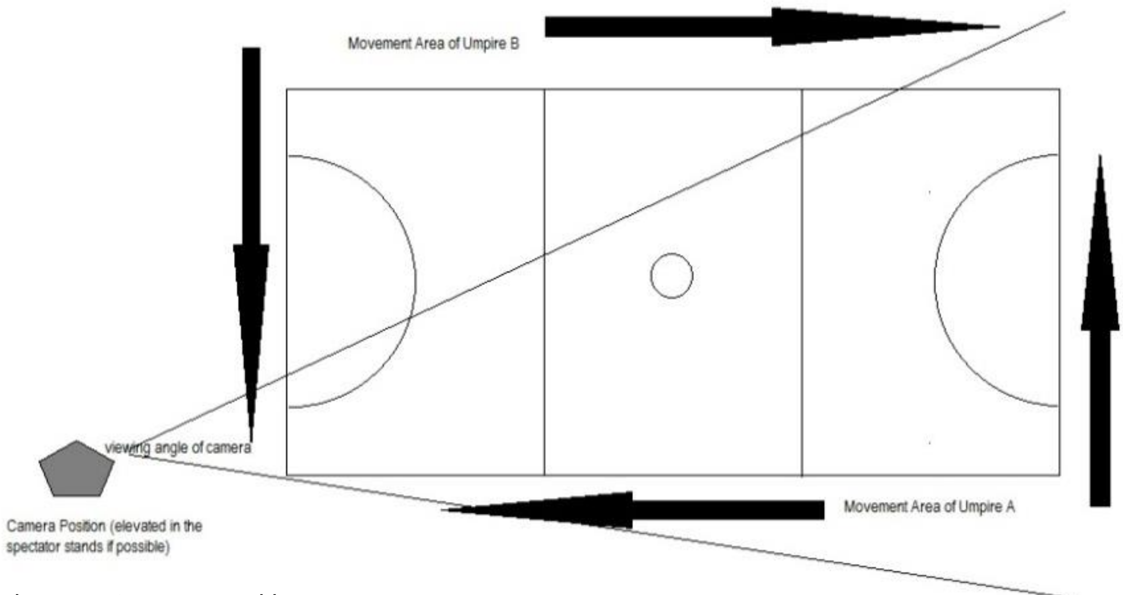

Figure 4, Camera Position

3.4 Fitness Testing Procedures

Fitness Testing took place pre and post season on dates specified by NNZ for availability of umpires (see Table 5). No familiarity tests were completed due to time constraints though 15 of the umpires had performed the fitness tests on a previous occasions. All fitness tests were conducted by the researcher, Natasha Paget except the pre-season testing of the National A and National Development Squads which were conducted by High Performance Sport New Zealand (HPSNZ) staff with assistance from Natasha Paget. Testing was undertaken at either the AUT Sports Stadium or the Te Pai Centre, Netball Waitakere in Auckland, NZ.

Table 5, Netball New Zealand pre and post-season fitness test dates and venues.

Date	Squad	No. of Umpires present	Venue
Pre-Season			
22-Apr-12	National A	5	Te Pai Centre
	National Development	7	Te Pai Centre
Post-Season			
5-Aug-12	ANZC	2	AUT Sports Stadium
23-Sep-12	ANZC	5	AUT Sports Stadium
26-Jan-13	National A	6*	AUT Sports Stadium
	National Development	4	AUT Sports Stadium
23-Mar-13	National A	1*	AUT Sports Stadium
	National Development	3	AUT Sports Stadium

** note that one umpire attended post-season testing on both the 26 January and 23 March 2013 as could only complete two out of the three tests on the first date.*

3.5 Fitness Test Definitions

Participants were required to complete three fitness tests in accordance with NNZ protocols:

1) 5m,10m, 20m Straight Line Sprint Test (Speed)

2) Octorepeater

3) Yo Yo Intermittent Recovery Test Level One (Yo Yo)

5m, 10m & 20m Straight Line Sprint:

The purpose of this test was to assess the umpire's straight-line quickness, speed and acceleration. Timing lights were stationed at 5, 10 and 20 meter intervals. Umpires were required to sprint through the lights in a straight line using a standing start and a slow walk back with a 3 minute rest before the next sprint. The fastest time of 3 attempts was recorded as the final test result. NNZ high performance squad umpires were required to score less than 3.75sec for the total sprint (Netball New Zealand, 2012). This test has been proven to be reliable for test – re-testing with an ICC = 0.84 to 0.96 (Gabbett, Kelley, & Sheppard, 2008).

Octorepeater:

The Octorepeater is a repeated sprint or anaerobic test, developed by HPSNZ (Netball New Zealand, 2012). The purpose of this test was to assess the umpire's ability to perform repeated maximal sprints that incorporate a change of direction. The Octorepeater test consists of eight sprints starting at 25 second intervals. The umpires completed 4 x (2 x 20) sprints and 4 x (4 x 10) sprints alternating between the 2 x 20m and 4 x 10m sprints. The umpire's final score is the combined time of the eight sprints. NNZ high performance squad umpires were required to score as follows, males <70sec and females <75sec (Netball New Zealand, 2012). No reliability data is available for this fitness assessment.

Yo-Yo Intermittent Recovery Test Level One:

The Yo-Yo intermittent recovery test (Yo Yo) level one is a valid and reliable aerobic fitness test which assesses the ability to sustain repeated high-intensity bouts of exercise over an extended period of time, with limited (10s) recovery (Bangsbo et al., 2008). Umpires completed 2 x 20m shuttles with a 2x 5m recovery (walking) shuttle within a specific time period, signalled by a pre-recorded audio cue. The speed required to complete each shuttle incrementally increases with each level. It is widely used in team sports to determine sport-specific aerobic performance (Bangsbo et al., 2008). The level achieved and distance covered (m) during the Yo Yo test determines the final score. The NNZ guideline for National A and National Development Squad umpires is to reach level 17.5 (Netball New Zealand, 2012). This fitness assessment has been proven reliable by both Thomas et al., (2006) (r = 0.95) and Krustrup et al., (2006) (r = 0.93).

All umpires received the Catapult mini-max vest, HR strap and transmitter on arrival. The GPS unit was turned on and placed in each umpires pouch in the vest within the 5 min prior to the start of each fitness and removed and turned off immediately after the umpire had completed their fitness test.

Prior to each test a check was made to ensure the HR strap was in position and sending a signal by using a Polar HR FT1 (Polar Electro Oy, Kempele, Finland) watch to receive the heart rate signal and show beats per minute (bpm). Each fitness assessment was filmed using a Canon LEGRIA HV40 video camera in a location which allowed the capture of all movements during each test.

Each participant performed their own specific warm up based on their match-day warm up. For the Speed and Octorepeater tests participants were instructed to start each sprint with their foot 50cm behind the start line (a light beam of the first timing gate) and in a stationary and upright position with one foot forward and one back and no rocking. For the Yo Yo test participants were instructed to follow the directions on the audio CD.

Recovery time between tests followed High Performance Sport New Zealand's (HPSNZ) guidelines for Netball NZ. There was a minimum of 3 min rest between sprints, and a minimum of15 min rest between the Octorepeater and the Yo Yo test. Participants were instructed to perform each test to maximum ability. For the speed test, the time for three sprints was recorded and the quickest time used for analysis. For the Octorepeater and Yo Yo test only one test time was recorded.

4. Data Analysis

The number of match day GPS, video data and fitness test results are shown in table 6 below. A match consisted of four quarters (15 min each).

Table 6, Number of data recorded for fitness and match day observations

Fitness test	**Match GPS**	**Match Movement**	**Speed Test**	**Octorepeater**	**Yo Yo Test**
Group One	20	16	7	7	7
Group Two	18	16	13	13	13
Group Three	21	16	14	14	14
Total	59	48	34	34	34

4.1 Physical and Physiological Measures:

Catapult mini-max S4 GPS

The GPS data (match-play and fitness test) were uploaded into the Catapult Sprint Software (Catapult Sports, Victoria, Australia). The data was analysed by time periods (quarter and whole match) so that any significant changes or trends across a match (between quarters) would be revealed.

Player Load™ and Estimated Equivalent Distance were the physical variables calculated by the Catapult mini-max S4 GPS and used in the analysis.

Completed data was exported to Microsoft Excel (Office 2010) to calculate means and standard deviation.

Heart Rate

The Polar Team[2] Heart Rate transmitter is compatible with the Catapult GPS unit and provided heart rate measures which were downloaded in the Catapult Sprint Software.

Heart Rate variables used for analysis were:

a. Mean HR
b. Percentage of HRpeak
c. HR Zones (percentage of time) (see table 7).

Table 7, Custom HR Zones Weston et al., 2009).

Zone	Percentage of Maximal Heart Rate
1	<60%
2	60–75%
3	76–85%
4	86–93%
5	>93%

Only matches with complete HR data sets were used in the analysis. All HR data was exported to Microsoft Excel (Office 2010) for calculation of means and standard deviations.

4.2 Movement Measures:

A notational analysis of umpire match-play demands and fitness test performance (Octorepeater and Yo Yo) was analysed in this study (Table 8). One coder using, Sports Code Elite Version 10 (Sportstec, New South Wales, Australia) analysed all video footage post match/ testing using the Netball Umpire Movement Classification Model (2012).

Development of a Netball Umpire Movement Classification Model:

This study was unique as it did not mimic any previous umpire research, therefore required a new movement classification model designed specific to netball umpire performance. The new movement pattern classification system was based on the Bloomfield Movement Classification model (Bloomfield et al., 2004) and the only previous Netball umpire research (Otago et al., 1994). Bloomfields' model was simplified to use ten different movement types and three location areas (court area) as many movement types were not applicable to netball umpires, such as 'on the ball' type movements. The coding classification system utilised in this project also required simplification to increase reliability, as the less choice available increases the chance of repetition if multiple analysts were employed (Bloomfield, Polman, & O'Donoghue, 2007). Only six movement types were utilised by Otago et al., (1994) however an extra three movement types were found applicable for this current study in order to provide greater detail (see Table 8).

Table 8. Comparison of Movement Variables analysed in 2012 and 1994 Netball Umpire Research.

Current Study 2012 Movement Classification Model (for definitions see 4.2.2)	**Netball Umpire Study 1994 Movement Types Analysed (Otago et al., 1994)**
Walking Sideways	Walking: Strolling movement in a forward, backward of sideways direction, proceeding by steps
Walking Backwards	
Walking Forwards	
Standing	Standing: No movement, stationary, feet remaining motionless
Jogging	Jogging: Slow, steady running action where there is no obvious acceleration
Sidestep	Side Stepping: Sideways movement, using abduction/ adduction of the hips.
Sprint	Sprinting: Fast running action with small quick steps or longer strides, obvious effort and acceleration
Turn to Change Direction	Changing Direction: Any distinct/ noticeable deviation of straight line movement
Turn to Stop	
Other	

Familiarisation of this movement classification model occurred over 4 weeks, with one coder watching videos at 50% normal speed to code match play movements. After this familiarisation period reliability of the model was determined.

Reliability

Reliability testing provides the degree of agreement between two separate data analysis, and how reliable the system used is to produce the same results. Intra-operator reliability was determined using the Intraclass Correlation Co-efficient (ICC) (Hopkins, 2000).

Reliability to ensure the consistency in the application of the definitions of coding was confirmed by coding one ANZC quarter (15min) on two separate occasions by the same analyst. Intra-class Correlation Coefficient (ICC) were calculated for the movement patterns (walking forwards, backwards, sideways, standing, jogging, sidestepping, turn to change direction and sprinting) with the percentage of time spent performing each movement (ICC = 1, CI: 0.99 to 1) and the frequency of movements (ICC=0.99, CI: 0.97 to 1). With one as the highest level of agreement, and zero as the lowest, in both cases the agreement level was very high therefore indicating a high level of reliability (table 9).

Table 9. Reliability for the 2012 Netball Umpire Movement Classification System

	Intra Class Correlation Coefficient (ICC)	**Lower Confidence Limit**	**Upper Confidence Limit**
Percentage of Time	1.00	0.99	1.00
Frequency	0.99	0.97	1.00

Description of Movement Variables:

The following variables (adapted from Bloomfield, 2004) were used to determine movement of umpires during match play.

Standing: stationary area with one foot remaining motionless. The other foot may lift off the ground and be replaced as long as one foot does not move.

Walking: walking/ strolling movement where one foot is lifted and moved in a direction, followed by the second foot and ground is covered.

Specific Walking Labels:

Forwards: one foot directly in front of the other with hips facing forwards when moving

Backwards: one foot directly behind the other moving in a backwards direction with hips still facing forwards

Sideways: one foot may cross the other, moving in any other direction except forwards or backwards. Hips may be rotated in either direction.

Jogging: slow, steady running action where there is no obvious acceleration and in a forwards motion

Sprinting: fast running action with small quick steps or longer strides, obvious effort and acceleration in a forwards motion

Side Step: Sideways movement, using abduction/adduction of the hips with the same intensity of jogging or sprinting.

Turn to stop: from a movement at speed into a rotation which changes movement type and slows down

Turn to change direction: from a movement at speed into a rotation which changes direction but maintains a similar speed of movement

Other: All other movement types that cannot be categorised.

Due to less than 1% of time spent and minimal frequency of performing the ‘Turn to stop’ and ‘Other’ movement types (ANZC <1%, Nat A and Nat Dev = 0%), these two movement types were not included in the analysis.

Work/ Rest-Recovery:

The movement variables above were categorised as either Work or Rest/recovery (see table 10) determined by the intensity of the activity (Davidson & Trewartha, 2008).

Table 10. Work and Rest-Recovery grouped Variables.

Work	**Rest-Recovery**
Jog	Standing
Sidestep	Walk Forwards
Sprint	Walk Backwards
Turn to Change Direction	Walk Sideways

4.3 Fitness Test Measures

Time(s) for both the speed and Octorepeater test and distance (m) based on the Yo Yo test level accomplished were transferred to Microsoft Excel (Microsoft Office, 2010) to calculate mean and standard deviations.

Statistical Analysis

Between-umpire mean ± standard deviations were determined for all variables to describe the distribution of data at two levels 1) Total (all umpires) and 2) Umpire Group (ANZC, Nat A and Nat Dev). The Shapiro Wilk test for normality tested for normal distribution of data and any variables that were significant were treated with non-parametric tests. A variety of tests were adopted, due to some data violating assumptions required for specific tests (i.e lack normal distribution and homeogenity of variance).

For parametric data comparisons between groups were determined using a one-way between-groups analysis of variance (ANOVA). Post Hoc comparisons, using the Tukey HSD test were conducted on the analysis for the three groups in order to specify where the differences occurred. The Kruskal-Wallis Test was used to compare groups for those individual variables who did not meet the assumptions for a parametric test and a Mann-Whitney U Test determined between which groups the differences occurred.

For parametric data comparison within groups were determined using a one-way repeated measures analysis of variance (ANOVA) across the four quarters of a match at both data levels. For all other data the Friedman and Wilcoxen Signed Rank non-parametric tests were used.

The interrelationships between variables of interest for the total group (all umpires) were determined with Pearson's product-moment correlation (r) for normally distributed data, for all other data Spearman's RHO was used.

For all tests statistical significance was set at an alpha value of $p < 0.05$ unless a Bonferroni correction was required (for multiple pairwise comparisons), then the adjusted p values is $p < 0.0125$.

IBM SPSS Version 22 (IBM Inc, Armonk, NY: IBM Corp) was used for all analyses except for Intraclass Correlation Coefficient (Hopkins, W.G. 2000). Intraclass Correlation Co-efficient (ICC) was used to assess the test-retest reliability of video analysis and movement pattern classification system.

The magnitude of difference in means (Cohen's *d*) are described with effect sizes (ES) using the following thresholds: trivial (< 0.19), small (0.20 – 0.59), moderate (0.60 – 1.19), large (1.20 – 1.99) and very large (2.00 - 4.00) (Chandler et al., 2014).

The magnitude of correlation (*r*) is described using the ES as follows: trivial (< 0.10), small (< 0.10 - 0.29), moderate (0.30 - 0.49), large (0.50 - 0.69), very large (0.70 - 0.89), nearly perfect (0.90 - 0.99). (Hopkins, Marshall, Batterham, & Hanin, 2009).

Chapter Four: Results

The results will be presented in three sections based on the three research questions.

> Section One: What are the movement patterns, physical and physiological demands of match day performance for high performance netball umpires?
>
> Section Two: Is there variance in the movement patterns, physical and physiological demands between higher and lower ranked umpires?
>
> Section Three: Does umpire performance in the Netball New Zealand (NNZ) specified fitness tests correlate with the movement, physical and physiological demands expressed during competition?

All results are presented as mean (± SD) unless otherwise stated.

Section One:

What are the physical, physiological and movement demands of match day performance for high performance netball umpires?

In order to answer the above research question, the results in this section will present the mean (± SD) for each variable and any significant changes between quarters for the total group (N = 22).

1. Physical Demands

Accumulated Player Load™ (PL)

PL was 407.3 ± 66.21 for the duration of a total match for all umpires. The mean PL across quarters are presented in figure 5. The ANOVA results show that PL significantly varied with time, $F\ (3, 55) = 3.42$, $p = .02$. Further analyses revealed that the umpires in Q2 (104.36 ± 20.67) had a significantly greater PL exertion (>5%) than in Q4 (99.02 ± 20.35), $p = .01$, $d = .26$ (small ES).

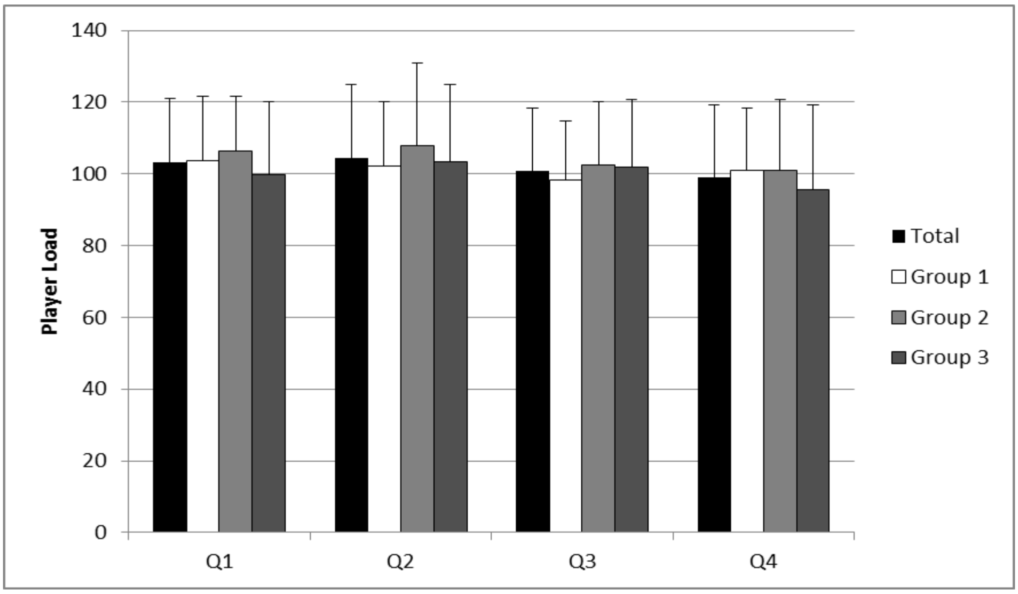

Figure 5, Accumulated Player Load across the duration of a match (quarters).

Estimated Equivalent Distance (EED)

EED was 3838 ± 613.8m for the duration of a total match for all umpires. The mean EED for each quarter are presented in figure 6. The ANOVA revealed that this variable significantly varied with time, $F (3, 56) = 3.18$, $p = .03$.Further analysis revealed that umpires in Q2 (981.5 ± 181.6m) had a 5% greater EED than in Q4 (934.4 ± 192.2m) although this was not considered statistically significant ($p = .05$, $d = .25$, small ES).

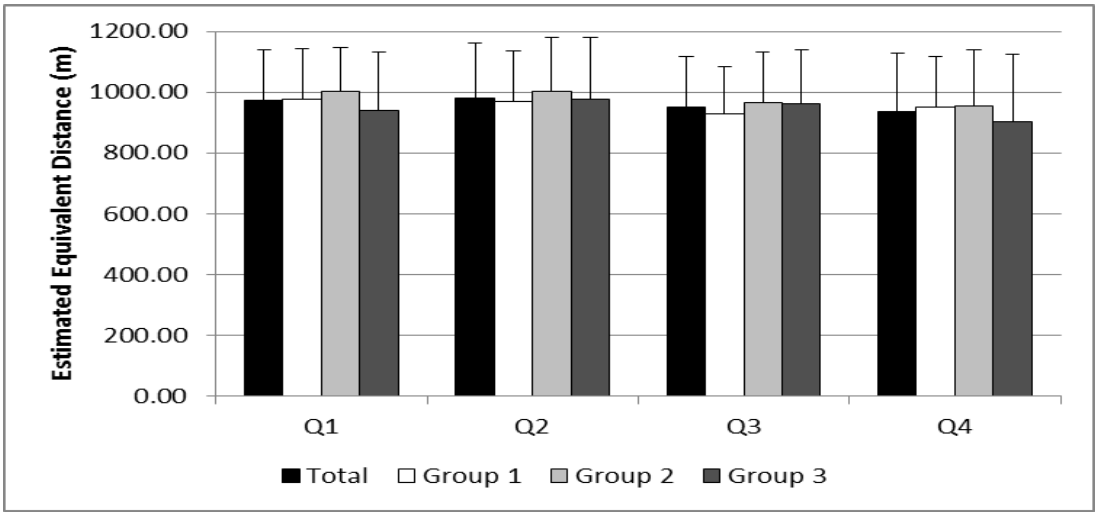

Figure 6, Estimated Equivalent Distance (m) across the duration of a match (quarters)

2. Physiological Demands

Mean Heart Rate (HR)

Mean HR shows a trend of decreasing across the four quarters (157 – 152.6bpm) for all umpires. The mean HR for each quarter are presented in figure 7. The ANOVA results revealed there was a significant difference for Mean HR across time, $F (3, 53) = 9.93$, $p < .000$.
Q1 (157.0 ± 13.07 bpm) had a 2% significantly greater mean HR than Q3 (153.7 ± 13.06 bpm), $p = .01$, $d = .31$ (small ES) and 3% greater than Q4 (152.6 ± 14.1bpm), $p = .002$, $d = .32$ (small ES). It was also revealed that Q2 (155.8 ± 12.37bpm) had a mean HR 2% significantly greater than Q4, $p = .003$, $d = .24$ (small ES).

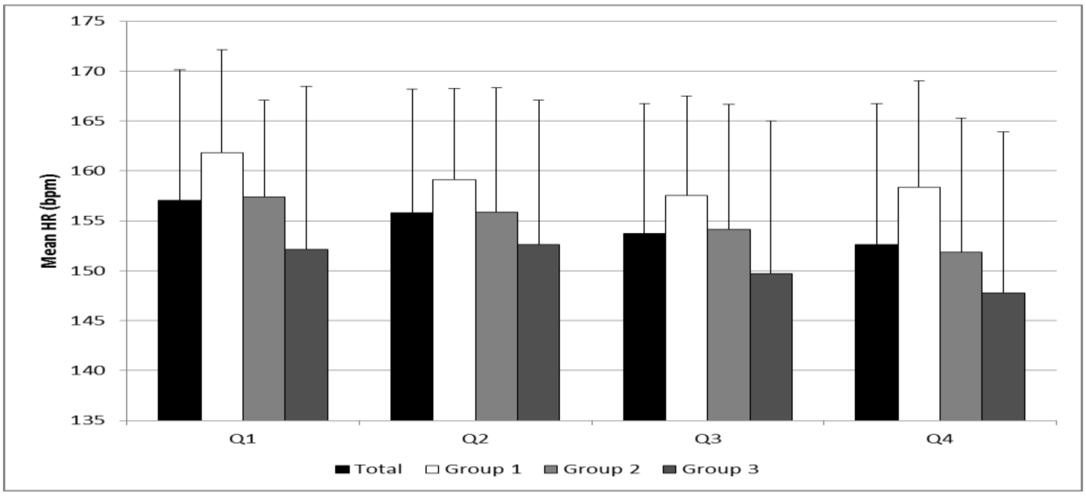

Figure 7, MeanHR (bpm) across the duration of a match (quarters).

Percentage of HRpeak

There was a trend of decreasing percentage of HRpeak across the quarters with an overall mean of 80.17 ± 7.13% for all umpires. The mean percentage of HRpeak for each quarter are presented in figure 8.

The ANOVA results confirmed a significant variance with time, $F(3, 53) = 10.28$, $p < .000$. Further analysis revealed that Q1 (81.34 ± 7.51%) was 2% significantly greater than Q3 (79.59 ± 7.26%), $p = .002$, $d = .24$ (small ES) and 3% significantly greater than Q4 (79.04 ± 7.76%), $p = .001$, $d = .30$ (small ES). It was also revealed that Q2 (80.72 ± 7.51%) had a significant 2% greater percentage of HRpeak than Q4 (79.04 ± 7.76%), $p = .002$, $d = .22$ (small ES).

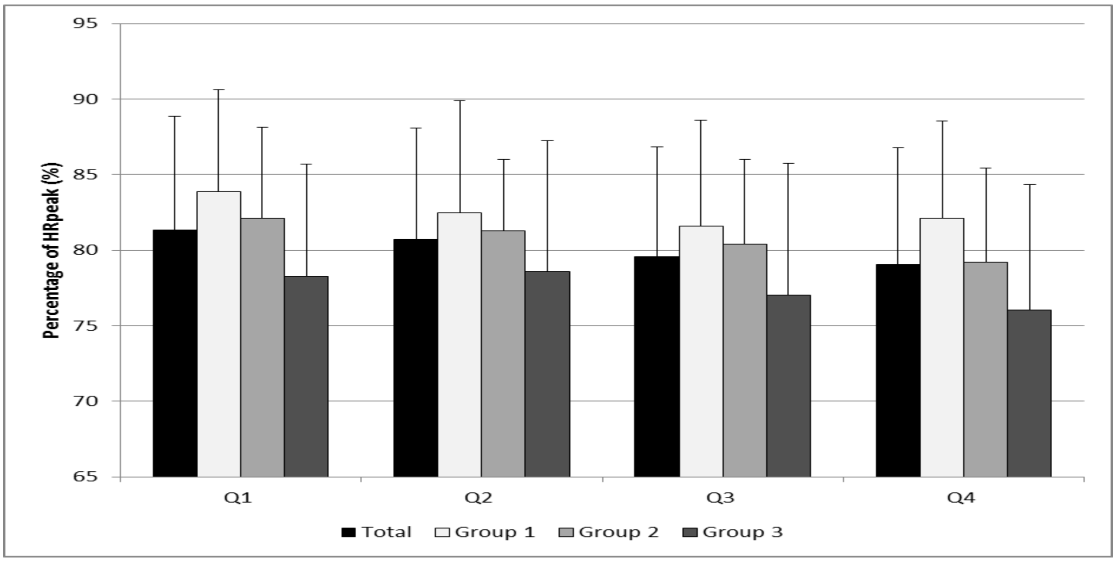

Figure 8, Percentage of HRpeak across the duration of a match (quarters)

Heart Rate Zones

Mean umpire HR was recorded in Zone 3 (75-85% of HRpeak) for the majority of time during a match (35%). Time spent in both Zone 2 (60-75% of HRpeak) and Zone 4 (85 – 94% of HRpeak) was 26% and 28% respectively (Fig 9). The least amount of time was spent in both HR Zone 1 (3%) and Zone 5 (8%).

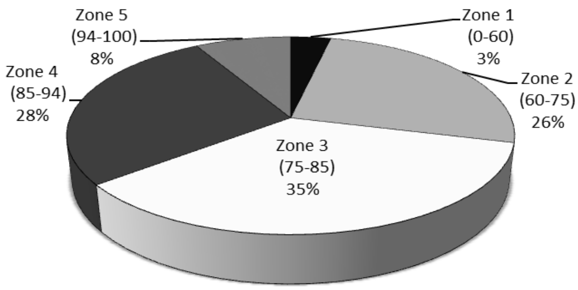

Figure 9, Percentage of time spent in each HR Zone during a match.

There was a statistically significant difference per quarter for the percentage of time spent in HR Zone 2 χ^2 (3) = 8.91, *p* = .03; Zone 4 χ^2 (3) = 13.6, *p* = .004 and Zone 5 χ^2 (3) = 14.95, *p* = .002 with the significant differences between quarters presented below.

HR Zone 2 (60-75%)

Umpires spent significantly less time in HR Zone 2 during Q1 (21.41 ± 23.35%) than Q2 (24.39 ± 20.03%), *Z* = -2.02, *p* = .04, *r* = .19 (small ES), Q3 (26.25 ± 23.88 %), *Z* = -2.68, *p* = .007, *r* = .25 (small ES), and Q4 (28.09 ± 23.29 %), *Z* = -2.87, *p* = .004, *r* = .27 (small ES).

There was also a significantly lower percentage of time spent in Q2 than in Q4, *Z* = -2.14, *p* = .03, *r* = .20 (small ES) (Fig 10).

HR Zone 4 (85 – 94%)

Umpires spent more time in HR Zone 4 during Q1 (30.77 ± 21.98%) than Q3 (23.71 ± 19.15%), *Z* = -3.33, *p* = .001, *r* = .31 (medium ES) and Q4 (23.88 ± 20.59%), *Z* = -2.92, *p* = .003, *r* = .28 (small ES).

HR Zone 5 (94 – 100%)

Lastly, umpires spent a greater percentage of time in HR Zone 5 during Q2 (10.66 ± 18.2%) than Q3 (8.18 ± 17%), *Z* = -2.92, *p* = .003, *r* = .28 (small ES), and Q4 (7 ± 13.78%), *Z* = -2.92, *p* = .004, *r* = .28 (small ES) (Fig 10).

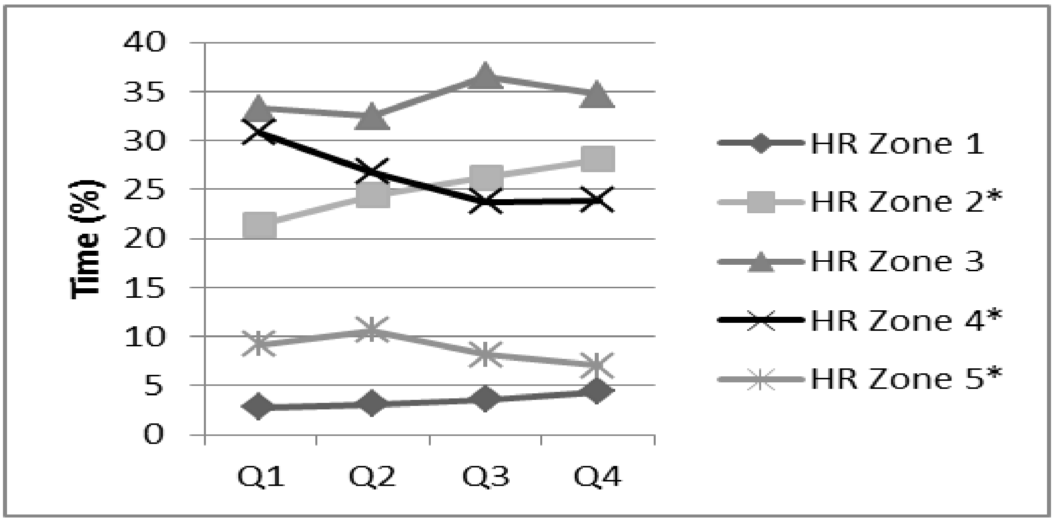

Figure 10, Percentage of time spent in each HR Zone per quarter.
**Significant (p < .05) difference between quarters.*

3. Movement Demands

Work/ Rest-recovery

The mean ± standard deviation for frequency, mean time and percentage of time are presented in table 11 below.

Table 11, Mean ± SD for Frequency, Mean Time and Percentage of time spent performing Work and Rest-Recovery movements

	Frequency	**Mean Time (s)**	**Percentage of Time (%)**
Rest-recovery	1080.63 ± 131.96	2.37 ± 0.22*	76.99 ± 5.94
Work	438.42 ± 105.04*	1.84 ± 0.16∞	19.48 ± 3.6*

**Denotes a statistically significant p < 0.05 difference across quarters*
∞Includes mean time for Jog, Sidestep and Sprint only.

There was significant variance of *work* across the four quarters for both frequency (χ^2 (3) = 8.17, *p* = .04) and percentage of time (χ^2 (3) = 11.17, *p* = .01). The ANOVA also revealed a significant difference between quarters for mean time spent performing *rest-recovery* movements, *F (3, 44)* = 8.91, *p* < .001. Further detail on these significant differences is explained below.

Frequency

A greater frequency of *work* was performed in Q1 (114.23 ± 27.07) than Q3 (107.92 ± 29.70), *Z* = -2.07, *p* = .04, *r* = .30 (moderate ES) and Q4 (106.06 ± 29.66), *Z* = -2.92, *p* = .003, *r* = .42 (moderate ES). There was also a greater frequency of *work* in Q2 (112.42 ± 29.23) than in Q4, Z = -2.30, p = .02, *r* = .33 (moderate ES) (Table 11).

Percentage of Time

A higher percentage of *work* was performed in Q1 (20.68 ± 4.65%) than Q2 (19.25 ± 4.16%) *Z* = -2.50, *p* = .01, *r* = .36 (moderate ES), Q3 (19.37 ± 4.16%), *Z* = -2.46, *p* = .01, *r* = .36 (moderate ES), and Q4 (19.03 ± 4.43%), *Z* = -2.83, *p* = .005, *r* = .41 (moderate ES) (Table 11).

Mean Time

Mean time spent performing *rest-recovery* was less during Q1 (2.25 ± 0.28s) than Q2 (2.42 ± 0.27s), *p* < .001, *d* = .62 (moderate ES), Q3 (2.39 ± 0.27s), *p* < .001, *d* = .51 (small ES) and Q4 (2.44 ± 0.27), *p* < .001, *d* = .69 (moderate ES) (Table 11).

Individual Movements

The mean ± standard deviation for frequency, mean time and percentage of time spent performing each of the individual movements are present in table 12 below.

Table 12, Mean ± SD for Frequency, Mean Time and Percentage of Total Time spent performing individual movement variables

	Frequency	**Mean Time (s)**	**Percentage of Time (%)**
WS	296.79 ± 85.36	1.33 ± 0.16*	9.92 ± 3.19
WB	70.29 ± 49.87	1.47 ± 0.30*	2.66 ± 2.10
WF	259.92 ± 62.8	2.30 ± 0.52*	15.15 ± 4.88
ST	453.63 ± 38.4*	4.40 ± 0.75*	49.27 ± 7.3
J	132.73 ± 53.27	1.61 ± 0.26	5.40 ± 2.4
TCD	38.4 ± 36.52	†	0.38 ± 0.35
SS	126.90 ± 69.95*	1.21 ± 0.23	3.99 ± 2.36*
SP	140.4 ± 24.36	2.76 ± 0.26	9.71 ± 1.93

**Denotes a statistically significant p < 0.05 difference across quarters*
†Mean Time (s) for Turn to Change Direction not included due to the quickness of this specific movement (<1s in duration).
WS = Walk Sideways, WB = Walk Backwards, WF = Walk Forwards, ST = Standing, J = Jog, TCD = Turn to Change, SS = Sidestep, SP = Sprint

Frequency

The ANOVA results revealed a significant variance in movement frequency between quarters for both *sidestep* $F(3, 44) = 6.64$, $p = .001$ and *standing* $F(3, 44) = 3.72$, $p = .02$ (Table 12). Further analysis revealed a greater frequency of *sidestepping* in Q1 (35.29 ± 18.56) than Q4 (28.36 ± 18.3) $p < .001$, $d = .38$ (small ES). There was a 5% greater frequency of standing in Q2 (116.3 ± 12.2) than Q3 (111.3 ± 11.43), $p = .03$, $d = .42$ (small ES).

Mean Time

There was a significant variance in the mean time spent performing each movement across quarters for the following movements; *walking sideways*, *walking backwards, walking forwards* and *standing* (Table 12).

Walking sideways significantly varied across time, $F(3, 44) = 4.0$, $p = .01$ with 5% less time per movement in Q1 (1.29 ± 0.16s) than in Q4 (1.36 ± 0.17s), $p = .02$, $d = .42$ (small ES). *Walking backwards* varied significantly across the quarters, $\chi^2(3) = 8.97$, $p = .03$ with shorter durations in Q1 (1.39 ± 0.42s) than in Q2 (1.51 ± 0.35s), $Z = -3.08$, $p = .002$, $r = .31$ (moderate ES).

Walking forwards varied significantly with time, $F(3, 44) = 4.43$, $p = .01$. Umpires spent 6% less time performing this movement in Q1 (2.21 ± 0.53s) than in Q3 (2.34 ± 0.55s), $p = .01$, $d = .24$ (small ES) and 7% less time than in Q4 (2.36 ± 0.56s) $p = .01$, $d = .28$ (small ES).

Finally *Standing* varied significantly across the four quarters, $F(3, 44) = 7.43$, $p < .001$. Umpires spent 11% less time *standing* in Q1 (4.1 ± 0.88s) than in Q2 (4.55 ± 0.88s), $p = .001$, $d = .51$ (small ES), 8% less time than in Q3 (4.41 ± 0.86s), $p = .01$, $d = .36$ (small ES) and 10% less time than in Q4 (4.54 ± 0.86), $p = .001$, $d = .51$ (small ES).

Percentage of Total Time

Umpires spent almost half a match in a stationary position or *standing* movement (49%). *Work* movements equate to only 23% of total time, however 10% of this is *sprinting* which is considered the highest intensity movement. (Fig11). Significant differences across the four quarters were found for *Sidestep*, $F(3, 44) = 3.85$, $p = .02$, with 20% more *sidestepping* occurring in Q1 (4.47 ± 2.72%) than in Q4 (3.62 ± 2.45%), $p = .03$, $d = .33$ (small ES).

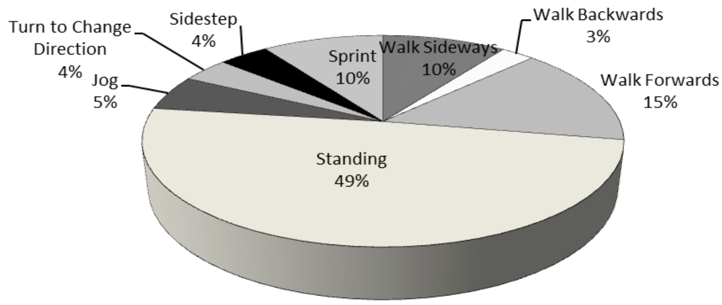

Figure 11. Percentage of time spent performing each movement (%).

Section Two:

Is there variance in the movement patterns, physical and physiological demands between higher and lower ranked umpires?

In order to answer the above research question, the results in this section are presented under each variable and state any significant differences between the three umpire groups.

1. Physical Demands

The mean ± standard deviation of Accumulated Player Load and Estimated Equivalent Distance for each Group are presented in table 13 below.

Table 13, Mean ± SD for GPS Variables; Accumulated Player Load™ and Estimated Equivalent Distance (m)

	Group 1	**Group 2**	**Group 3**
Accumulated Player Load™			
Match	405.10 ± 61.98	417.61 ± 66.73	400.67 ± 71.62
Q1	103.6 ± 17.9	106.39 ± 15.27	99.81 ± 20.3
Q2	102.2 ± 17.99	107.89 ± 23.12	103.38 ± 21.45
Q3	98.35 ± 16.5	102.39 ± 17.71	101.95 ± 18.79
Q4	100.95 ± 17.41	100.94 ± 19.68	95.52 ± 23.74
Estimated Equivalent Distance (m)			
Match	3825.5 ± 577.94	3922.83 ± 601.37	3779.71 ± 676.62
Q1	976.65 ± 168.12	10001.72 ± 145.66	940.76 ± 190.62
Q2	968.85 ± 168.36	1002.11 ± 177.91	976 ± 203.01
Q3	927.95 ± 154.98	965.39 ± 166.7	961.71 ± 177.17
Q4	952.05 ± 164.09	953.61 ± 186.66	901.24 ± 223.92

There were no significant difference between umpire level found for total match accumulated PL score $F(2, 58) = 0.33$, $p = .72$ nor EED $F(2, 58) = .264$, $p = .77$ (Table 13).

2. Physiological Demands

The mean ± standard deviation of Mean HR and Percentage of HRpeak for each group are presented in table 14 below.

Table 14, Mean ± SD for HR Variables; Mean HR (bpm) and Percentage of HRpeak (%)

Group	Group 1	Group 2	Group 3
Mean Heart Rate (bpm)			
Match	159.21 ± 9.47	154.82 ± 11.43	150.56 ± 14.63
Q1	161.84 ± 10.28*	157.41 ± 9.68	152.15 ± 16.34
Q2	159.11 ± 9.18	155.88 ± 12.44*	152.6 ± 14.52
Q3	157.53 ± 9.99*	154.12 ± 12.58	149.7 ± 15.3
Q4	158.37 ± 10.63	151.88 ± 13.41*	147.8 ± 16.1
Percentage of HRpeak (%)			
Match	82.51 ± 6.88[b]	80.75 ± 5.28	77.47 ± 8.1[b]
Q1	83.89 ± 7.43*[b]	82.13 ± 4.7*	78.25 ± 8.68[b]
Q2	82.47 ± 7.01	81.29 ± 5.6*	78.58 ± 8.75
Q3	81.59 ± 6.43*	80.4 ± 6.23	77 ± 8.31
Q4	82.08 ± 7.41[ab]	79.19 ± 6.09*	76.03 ± 8.5[ab]

**Denotes a statistically significant ($p < .00$) difference between Quarters*
[a]Denotes a statistically significant ($p < .05$) difference between Group 1 and Group 2
[b]Denotes a statistically significant ($p < .05$) difference between Group 1 and Group 3
[c]Denotes a statistically significant ($p < .05$) difference between Group 2 and Group 3

Mean Heart Rate

There were no significant differences in mean HR between umpire groups for the duration of a whole match, $F(2, 55) = 2.486$, $p = .09$ (Table 14).

Percentage of HRpeak

There was a significant difference found between umpire groups for the percentage of HRpeak during a match: $F(2, 55) = 4.21$, $p = .02$, with further analyses indicating that Group One (82.51 ± 6.88%) was 2% higher than Group Three (77.47 ± 8.68%), $p = .02$, $d = .70$ (moderate ES) (Table 14).

Heart Rate Zones

The mean ± standard deviation of each HR Zone for each group are presented in figure 12 below.

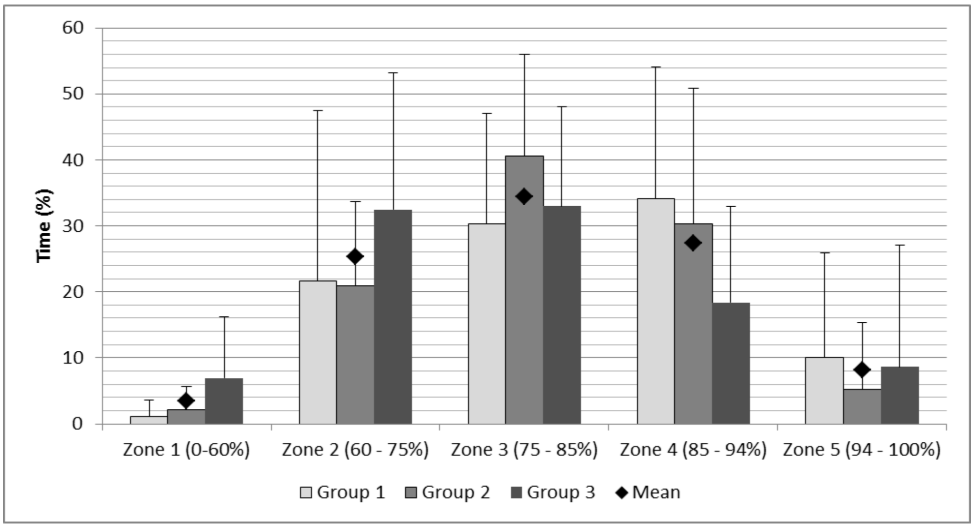

Figure 12. Time spent in each Heart Rate zone as a percentage (%) per Group

For a total match the ANOVA was statistically significant in HR Zone 4, indicating that the percentage of time spent in this HR Zone was influenced by umpire level, $F(2, 55) = 3.85$, $p = .03$. Post hoc analyses revealed that Group One (34.11 ± 19.96%) had spent significantly more time in HR Zone 4 than Group Three (18.4 ± 14.47%), $p = .03$, $d = .90$ (moderate ES) (Fig 12).

3. Movement Demands

Work/ Rest-recovery

The mean ± standard deviation of frequency, mean time and percentage of time for both work and rest-recovery variables for each groups are presented in table 15 below.

Significant differences between groups were revealed for overall *rest-recovery* for frequency ($F(2, 47) = 9.14$, $p < .001$), mean time ($F(2, 47) = 7.03$, $p = .002$) and percentage of total time ($\chi^2 (2, n = 48) = 6.56$, p = .04), however no significant differences between groups were revealed for overall *work*.

Table 15, Mean ± SD for Frequency, Mean Time and Percentage of time spent performing Work and Rest-Recovery movements for each group

Frequency	**Group 1**	**Group 2**	**Group 3**
Rest-recovery	1174.31 ± 149.51[cd]	1005.44 ± 79.91[c]	1062.13 ± 100.32[d]
Work	474.75 ± 96.42	433.06 ± 138.49	407.44 ± 60.25
Mean Time (s)			
Rest-recovery	2.23 ± 0.12[cd]*	2.41 ± 0.20[c]*	2.48 ± 0.25[d]
Work∞	1.8 ± 0.18	1.81 ± 0.13	1.91 ± 0.15
Percentage of Time (%)			
Rest-recovery	73.74 ± 7.39[c]	78.7 ± 4.88[c]	78.52 ± 3.90
Work	20.23 ± 3.60	19.54 ± 4.63*	18.67 ± 2.23

[c]*Denotes a statistically significant (p < 0.05) difference between Group 1 and Group 2.*
[d]*Denotes a statistically significant (p < 0.05) difference between Group 1 and Group 3.*
[e]*Denotes a statistically significant (p < 0.05) difference between Group 2.and Group 3.*
**Denotes a statistically significant p < 0.05 difference across quarters*
∞*Includes mean time for Jog, Sidestep and Sprint only.*

Frequency

Rest-recovery frequency for Group One (1174 ± 149.5) was greater than Group Two (1005 ± 79.9), $p < .001$, $d = 1.41$ (large ES) and Group Three (1062 ± 100.3), $p = .02$, $d = .88$ (moderate ES).

Mean Time

Mean Time spent performing *rest-recovery* Group One (2.23 ± 0.12s) was less than Group Two (2.41 ± 0.2s), $p = .03$, $d = 1.09$ (moderate ES) and Group Three (2.48 ± 0.25s), $p = .002$, $d = 1.27$ (large ES).

Percentage of Time

Lastly the percentage of time spent on overall *rest-recovery* was less for Group One (73.74 ± 7.39%) than Group Two (78.7 ± 4.88%), $U = 64$, $z = -2.41$, $p = .02$, $r = .43$ (moderate ES).

Individual Movements

The mean ± standard deviation of frequency, mean time and percentage of time spent performing individual movement variable for each group are present in table 16 below.

Table 16, Mean ± SD for Frequency, Mean Time and Percentage of Total Time spent performing individual movement variables for each group.

	Group 1	**Group 2**	**Group 3**
Frequency			
WS	343.19 ± 83.49^{c}	243.13 ± 60.59^{ce}	304.06 ± 82.25^{e}
WB	105.434 ± 55.15^{cd}	49.75 ± 22.34^{c}	55.69 ± 47.08^{d}
WF	263.56 ± 83.92	254.44 ± 59.77	261.75 ± 41.14
ST	462.13 ± 48.59	458.13 ± 28.13	440.63 ± 34.48
J	115.19 ± 45.97	136.25 ± 69.72	146.75 ± 36.95
TCD	68.44 ± 38.17^{cd}	12.5 ± 14.06^{ce}	34.25 ± 28.78^{de}
SS	147.31 ± 64.07	135.63 ± 80.86	97.75 ± 57.08
SP	143.81 ± 28.64	148.69 ± 21.27	128.69 ± 18.95
Mean Time (s)			
WS	1.42 ± 0.19^{c}	1.24 ± 0.13^{c}	1.33 ± 0.1
WB	1.61 ± 0.26^{c}	1.33 ± 0.23^{ce}	1.48 ± 0.36^{e}
WF	2.11 ± 0.51	2.33 ± 0.55	2.47 ± 0.47
ST	3.79 ± 0.40^{cd}*	4.74 ± 0.52^{c}	4.66 ± 0.85^{d}
J	1.49 ± 0.17^{d}	1.49 ± 0.17^{e}	1.84 ± 0.26^{de}
TCD	1.35 ± 0.17^{cd}	1.10 ± 0.21^{c}	1.17 ± 0.25^{d}
SS	2.88 ± 0.23^{d}	2.76 ± 0.18	2.63 ± 0.30^{d}
Percentage of Time (%)			
WS	11.92 ± 2.61^{c}	7.68 ± 2.41^{ce}	10.13 ± 3.11^{e}
WB	4.26 ± 2.36^{c}	1.66 ± 0.77^{c}	2.06 ± 1.90
WF	14.11 ± 5.19	15.26 ± 5.65	16.08 ± 3.68
ST	43.44 ± 6.98^{cd}	54.10 ± 4.77^{c}	50.26 ± 5.8^{d}
J	4.28 ± 1.75^{d}	5.06 ± 2.53	6.87 ± 2.21^{d}
TCD	0.69 ± 0.36	0.12 ± 0.01	0.33 ± 0.28
SS	5 ± 1.96^{d}	3.99 ± 2.68*	3 ± 2.08^{d}
SP	10.27 ± 1.81^{d}	10.38 ± 1.73	8.48 ± 1.71^{d}

^{c}Denotes a statistically significant ($p < 0.05$) difference between Group 1 and Group 2.
^{d}Denotes a statistically significant ($p < 0.05$) difference between Group 1 and Group 3.
^{e}Denotes a statistically significant ($p < 0.05$) difference between Group 2.and Group 3.
WS = Walk Sideways, WB = Walk Backwards, WF = Walk Forwards, ST = Standing, J = Jog, TCD = Turn to Change, SS = Sidestep, SP = Sprint

Frequency

Significant differences for movement frequency were found between groups for *walking sideways* (χ^2 (2) = 11.57, *p* = .003), *walking backwards* (χ^2 (2) = 10.97, p = .004), and *turn to change direction* (χ^2 (2) = 18.4, *p* < .001).

Group Two (243.1 ± 60.59) performed *walking sideways* less frequently than Group One (343.2 ± 83.49) *U* = 43, *Z* = -3.20, *p* = .001, *r* = .57 (large ES), and Group Three (304.06 ± 82.25), *U* = 68.5, *Z* = -2.24, *p* = .03, *r* = .40 (moderate ES).

Group One (105.4 ± 55.15) had approximately double the frequency of *walking backwards* to Group Two (49.75 ± 22.34) *U* = 47, *Z* = -3.05, *p* = .002 *r* = .54 (large ES), and Group Three (55.69 ± 47.08), *U* = 57.5, *Z* = -2.66, *p* = .01, *r* = .47 (moderate ES) (Fig 13).

The turn to change direction movement was performed more extensively by Group One (68.44 ± 38.17), than either Group Two (12.5 ± 14.06), *U* = 21, *Z* = -4.04, *p* < .000, *r* = .71 (very large ES) or Group Three (34.25 ± 28.78), *U* = 57, *Z* = -2.68, *p* = .01, *r* = .47 (moderate ES). Group Three performed this movement significantly more than those of Group Two, *U* = 75, *Z* = -2.001, *p* = .049, *r* = -.35 (moderate ES).

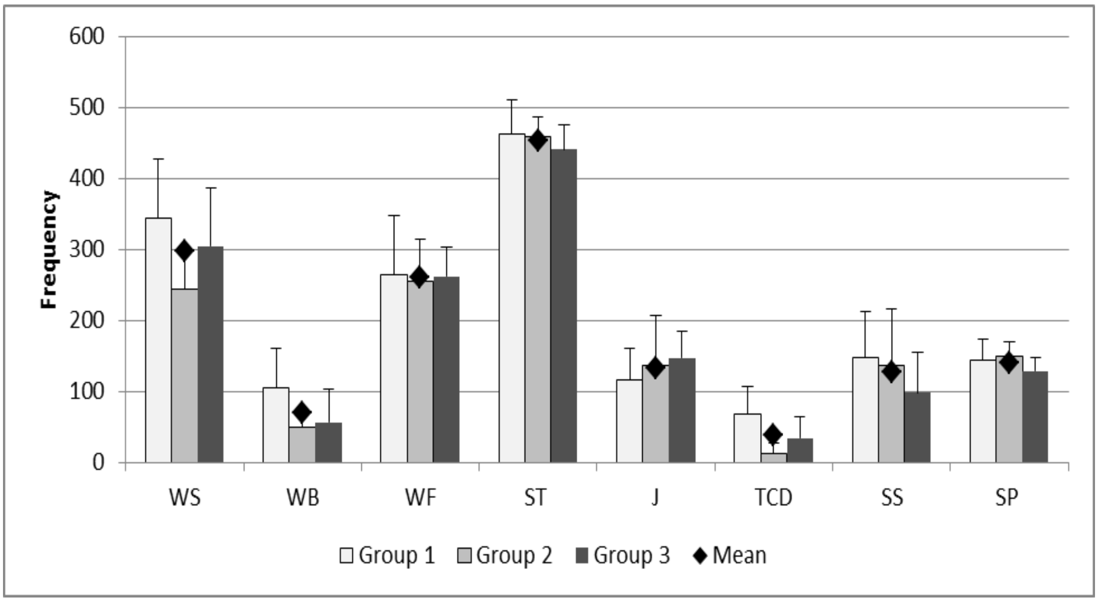

Figure 13. Comparison of frequency of individual movements for umpire groups. WS = Walk Sideways, WB = Walk Backwards, WF = Walk Forwards, ST = Standing, J = Jog, TCD = Turn to Change Direction, SS = Sidestep, SP = Sprint.

Mean Time

Numerous significant differences for the mean time spent performing movements were found to be influenced by umpire group. These movements were *Walking Sideways* (*F (2, 47)* = 5.91, *p* = .05), *Walking Backwards* (χ^2 (2) = 8.79, *p* = .01), *Standing (F (2, 47)* = 11.64, *p* < .001, *Jogging (F (2, 47)* = 14.67, p < .001), *Sidestepping (F (2, 47)* = 5.89, *p* = .01) and *Sprinting (F (2, 47)* = 4.37, *p* = .02).

NOTE: The mean time for the Turn to change direction movement does not provide relevant results due to the extreme quickness of the movement, and is significantly limited by the coder's reaction time and therefore results are not presented for this movement. This result is also not included in the overall work results as the extremely low score would bias the overall work mean and not give a true indication of the mean amount of time spent in work movements (sprint, jog and sidestep).

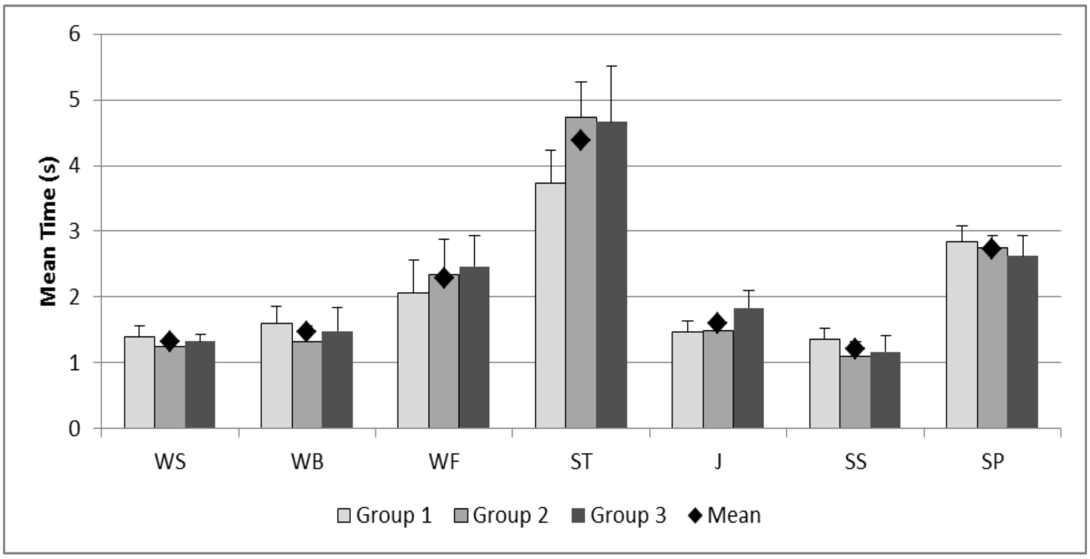

Figure 14 Mean time performing each individual movement. WS = Walk Sideways, WB = Walk Backwards, WF = Walk Forwards, ST = Standing, J = Jog, TCD = Turn to Change Direction, SS = Sidestep, SP = Sprint.

Group One (1.42 ± .19s) spent longer durations *walking sideways* than Group Two (1.24 ± .13s), p = .004, d = 1.12 (moderate ES). Group One (1.61 ± 0.26s), also spent longer durations *walking backwards* than Group Two (1.33 ± 0.23s), U = 47.5, Z = -3.04, p = .002, r = .54 (large ES).

Group One (3.79 ± 0.4s) spent significantly less time than Group Two (4.74 ± 0.52s) p < .001, d = 2.05 (very large ES) and Group Three (4.66 ± 0.85s) p = .001, d = 1.31 (large ES) *standing* during a match.

Group Three (1.84 ± 0.26s) spent 23% more time *jogging* than Group One (1.49 ± 0.17s), p < .001, d = 1.59 (large ES) and 23% more time than Group Two (1.49 ± 0.17s), p < .001 d = 1.59 (large ES).

Group One (1.35 ± 0.17s) spent significantly more time *sidestepping* than Group Two (1.1 ± 0.21s), p = .01, d = 1.31 (large ES), and Group Three (1.17 ± 0.25s) p = .04, d = .84 (moderate ES). Lastly Group One (2.88 ± 0.23s) spent significantly more time *sprinting* than Group Three (2.63 ± 0.30s) p = .01, d = .94 (moderate ES) (Fig 14).

Percentage of Total Time

Statistically significant differences for the percentage of time were found between groups for the following variables; *walking sideways (F (2, 47)* = 9.84, p < .001, *walking backwards* (χ^2 (2) = 12.41, p < .002)*, standing (F (2, 47)* = 13.32, p < .001)*, jogging (F (2, 47)* = 5.59, *p* = .01) and *sprinting (F (2, 47)* = 5.92, *p* = .01).

Group One spent more time *walking sideways* (11.94 ± 2.61%) than Group Two (7.68 ± 2.41%), p < .001, *d* = 1.70 (large ES), Group Three (10.13 ± 3.11%) also spent more time *walking sideways* than Group Two, *p* = .04, *d* = .88 (moderate ES).

The time spent *walking backwards* by Group One (4.26 ± 2.36%) was higher than Group Two (1.66 ± 0.77%), *u* = 39.5, z = -3.36, *p* = .001, *r* = .59 (large ES).

Group One (43.44 ± 6.98%) spent 25% less time *standing* than Group Two (54.1 ± 4.79%), *p* < .001, *d* = 1.78 (large ES) and 16% less time than Group Three (50.26 ± 5.8%) *p* = .01, *d* = 1.06 (moderate ES) (Fig 15).

Group One (4.28 ± 1.75 %) spent 60% less time *jogging* than Group Three (6.87 ± 2.21%), *p* = .01, *d* = 1.30 (large ES).

Group Three (8.48 ± 1.71%) spent 21% less time *sprinting* than Group One (10.27 ± 1.81%), *p* = .02, *d* = 1.12 (moderate ES) and 22% less time than Group Two (10.38 ± 1.73%), *p* = .01, *d* = 1.10 (moderate ES) (Fig 15).

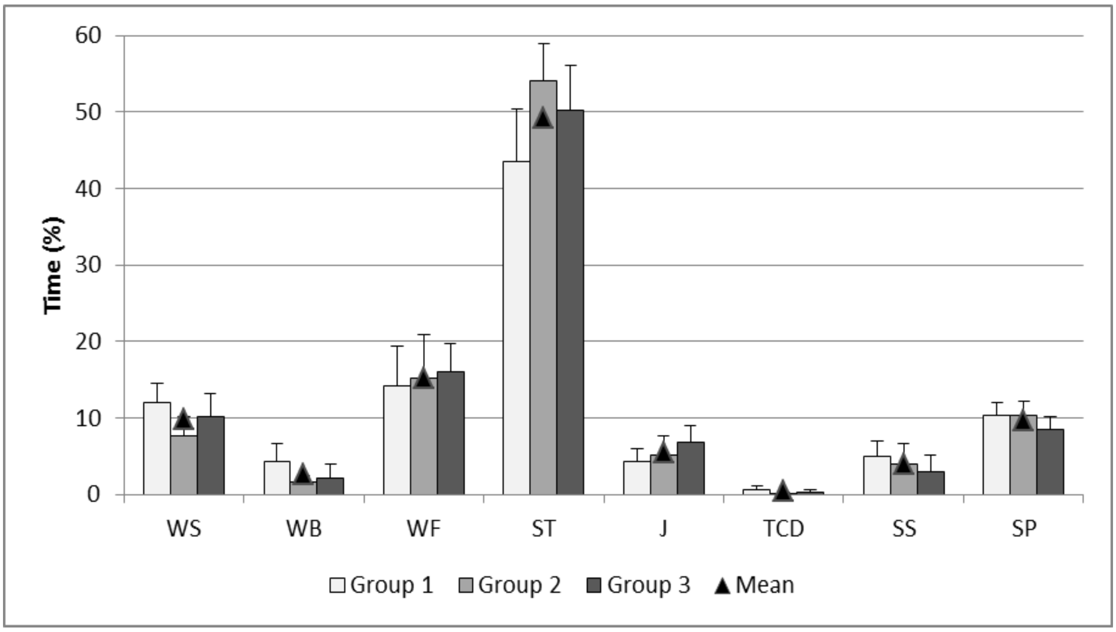

Figure 15, Percentage of time spent performing movements during a match. WS = Walk Sideways, WB = Walk Backwards, WF = Walk Forwards, ST = Standing, J = Jog, TCD = Turn to Change Direction, SS = Sidestep, SP = Sprint.

Section Three:

Does umpire performance in the Netball New Zealand (NNZ) specified fitness tests correlate with the movement, physical and physiological demands expressed during competition?

In order to answer this research question, the results will report on correlations between the following match-play and fitness test variables:

Fitness Test:

a. Results (Yo Yo Distance and Octorepeater Time)
b. Mean HR
c. Percentage and Mean Time performing Work, Jog and Sprint

Match-Play:

a. Mean HR
b. Percentage of HRpeak
c. Estimated Equivalent Distance,
d. Player Load™
e. Percentage and Mean Time performing Work, Jog and Sprint

The mean scores from the battery of fitness test for Total (all umpires), and three umpire groups are presented in table 17 below.

Table 17. Mean Fitness Test results for 2012 High Performance Netball Umpires

	Total	**Group 1**	**Group 2**	**Group 3**
Pre-Season				
Sprint 20m Time (s)	3.41 ± 0.24		3.44 ± 0.24	3.38 ± 0.26
Octorepeater Time (s)	74.80 ± 5.30		75.94 ± 5.14	74.05 ± 5.66
Yo Yo Distance (m)	1027 ± 454		816 ± 346	1177 ± 485
Post-Season				
Sprint 20m Time (s)	3.48 ± 0.22	3.58 ± 0.15	3.46 ± 0.22	3.41 ± 0.27
Octorepeater Time (s)	74.54 ± 4.72	71.31 ± 2.97	77.34 ± 4.55	75.35 ± 4.88
Yo Yo Distance (m)	933 ± 478	714 ± 310	861 ± 412	1177 ± 600

In all cases the pre-season fitness is greater than the post-season results. Group Three umpires show a greater aerobic fitness (further distance travelled in the Yo Yo Test) and greater speed overall. Group One umpires show a greater anaerobic capacity (Octorepeater Test).

Fitness test movement variables for frequency, percentage of time and mean time are presented in table 18 below.

Table 18, Mean time and Percentage of time per movement type for the Octorepeater and Yo Yo Fitness Tests

	Total	Group 1	Group 2	Group 3
Octorepeater Percentage of total time (%)				
Walk Forwards	27.93 ± 8.08	19.87 ± 9.84	32.5 ± 2.64	29.87 ± 6.39
Standing	19.38 ± 8.37	21.92 ± 9.27	15.88 ± 3.45	16.2 ± 7.54
Jog	6.15 ± 1.78	4.8 ± 0.66	5.54 ± 2.05	7.25 ± 2.00
Turn to change direction	6.72 ± 1.22	5.99 ± 1.20	6.09 ± 0.87	7.03 ± 1.42
Sprint	38.41 ± 2.28	34.48 ±1.75	37.35 ± 3.73	38.17 ± 1.07
Octorepeater Mean Time (s)				
Walk Forwards	5.09 ± 1.99	3.13 ± 0.90	5.65 ± 1.95	6.22 ± 2.04
Standing	5.12 ± 2.2	5.72 ± 2.58	4.13 ± 0.60	4.41 ± 1.98
Jog	1.79 ± 0.67	1.24 ± 0.19	2.05 ± 0.74	1.97 ± 0.83
Turn to change direction	0.6 ± 0.24	0.48 ± 0.10	0.51 ± 0.08	0.72 ± 0.36
Sprint	3.04 ± 0.17	2.71 ± 0.15	3 ± 0.28	3.02 ± 0.11
Yo Yo Percentage of total time (%)				
Walk Forwards	24.46 ± 5.13	22.96 ± 8.25	25.52 ± 2.89	25.19 ± 1.13
Standing	15.84 ± 7.44	20.43 ± 10.86	13.59 ± 3.50	12.87 ± 0.95
Jog	36.37 ± 10.31	34.53 ± 9.63	35.89 ± 8.80	38.55 ± 12.84
Turn to Change Direction	8.54 ± 1.66	6.89 ± 1.56	9.54 ± 1.05	9.48 ± 0.11
Sprint	16.62 ± 8.91	16.17 ± 7.89	18.47 ± 5.36	15.85 ± 12.45
Yo Yo Mean Time (s)				
Walk Forwards	3.61 ± 0.82	3.06 ± 1.06	3.66 ± 0.58	4.11 ± 0.17
Standing	2.93 ± 1.90	3.45 ± 2.80	2.89 ± 0.65	2.69 ± 0.12
Jog	4.27 ± 1.83	3.42 ± 2.03	5.17 ± 0.19	5.33 ± 0.01
Turn to Change Direction	0.77 ± 0.34	0.58 ± 0.36	0.99 ± 0.09	0.96 ± 0.02
Sprint	3.47 ± 2.19	2.98 ± 2.24	4.04 ± 2.29	4.19 ± 1.85

Relationship between Umpire Level and Fitness Test Measures

A moderate correlation was observed between umpire rank and the distance covered in the Yo Yo Fitness Test ($r = .51$, $p = .02$) (Fig 16).

Relationships between Fitness Tests and Umpire Match Performance

The correlations between fitness and match-play variables are presented in Table 19.

Table 19. Correlation coefficients for Fitness Test and Match-play Variables.

	PL	**EED**	**MT Work (s)**	**% Time Work**	**% Time Jog**	**%Time Sprint**	**MT Sprint**	**Freq TCD**	**% HR peak**	**MHR**
Fitness Test Results										
YYD	.31	.31	.03	.15	.51*	-.03	-.43	-.20	-.19	-.13
OT	-.06	-.06	.22	.14	.07	.17	.28	.16	.31	.10
ST	-.02	-.01	.16	.13	.06	.22	.32	.21	.43	.18
Fitness Test Physical and Physiological Demands										
Yo Yo										
%Time Sprint	.15	.15	-.31	-.09	.09	.02	-.32	-.18	-.29	-.51*
%Time Jog	-.30	-.31	.33	.05	-.05	-.15	.37	.26	.21	.12
%Time Work	-.10	-.11	.12	.11	.32	-.29	-.38	-.38	-.34	-.03
MHR	.06	.06	.62**	.59**	.02	.02	-.22	-.10	-.34	.38
Octorepeater										
Freq TCD	-.01	-.01	-.41	-.18	.37	-.19	-.16	.48*	.17	.02
%Time Sprint	.07	.07	-.20	-.02	-.12	.19	.23	.10	.45	-.01
MT Sprint	.08	.08	-.15	.03	-.22	.26	.21	-.03	.34	-.10
%Time Work	-.05	-.05	-.13	-.11	.06	-.09	.02	-.06	-.11	-.29
MT Work	-.10	-.10	.07	-.08	.06	-.15	-.04	-.45	-.35	-.40
MHR	.00	-.01	.43	.49*	.04	-.01	-.15	.08	-.35	.47*

***. Correlation is significant at the 0.01 level (2-tailed).*
**. Correlation is significant at the 0.05 level (2-tailed).*
[a]*Spearman's RHO correlation co-efficient*
Note: unless specified Pearson's Product-Moment Correlation Coefficient is reported.
WS = Walk Sideways, WB = Walk Backwards, WF = Walk Forwards, ST = Standing, J = Jog, TCD = Turn to Change Direction, SS = Sidestep, SP = Sprint

The key significant correlations found were as follows:

For the Yo Yo test a large correlation was found between the distance travelled in the Yo Yo Test and the percentage of time spent *jogging* during match-play (r = .51, p = .03) (Fig 17). A large correlation was found between the mean HR in the Yo Yo Test and match-play mean time spent *working* (r= .62, p = .004)(Fig 20) and the percentage of time spent *working* (r = .59, p = .01) (Fig 18). Lastly a large negative correlation was found between the percentage of time spent *sprinting* during the Yo Yo fitness test and match-play mean HR (r = -.51, p = .04) (Fig 19).

Relationships between the Octorepeater test and match-play variables revealed a moderate correlation between the frequency of the *Turn to Change Direction* movement in match-play and the Octorepeater fitness test (r = .48, p = .05) (Table 19). Finally a large correlation was found between the mean HR in the Octorepeater test and both the percentage of time spent *working* (r = .50, p = .03) (Fig 21) and the mean HR (r = .47, p = .04) (Fig 22) during match-play.

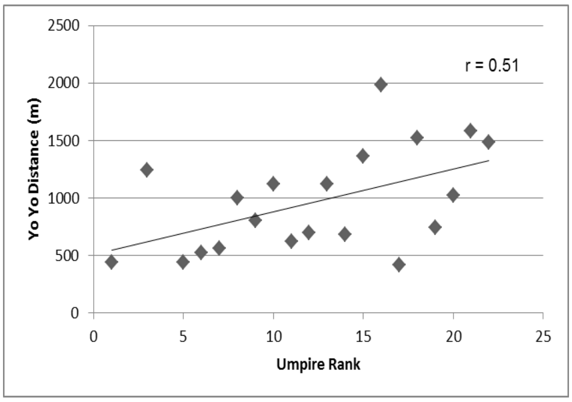

Figure 16, Relationship between Yo Yo Distance (m) and Umpire Rank

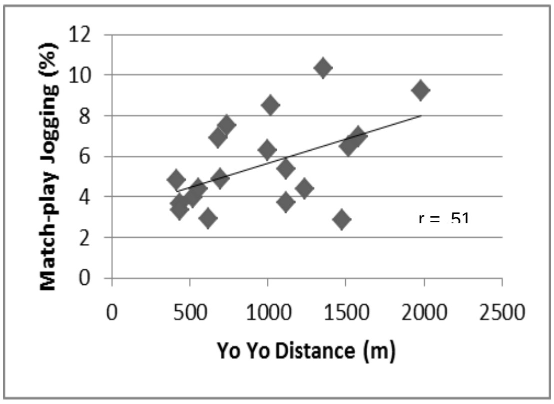

Figure 17, Relationship between Yo Yo Distance (m) and match-play jogging (%)

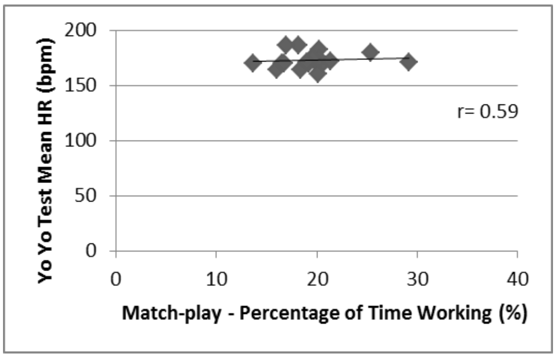

Figure 18, Relationship between Yo Yo Mean HR (bpm) and Match-play Working (%)

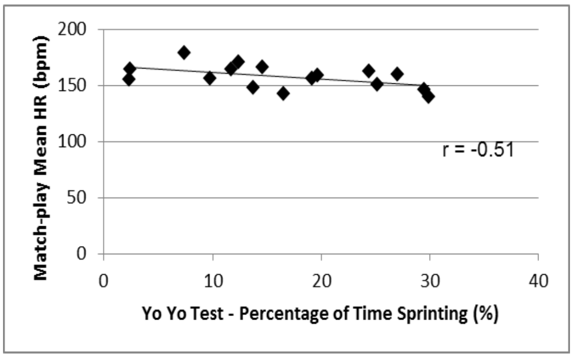

Figure 19, Relationship between Yo Yo Sprinting (%) and Match-play Mean HR(bpm)

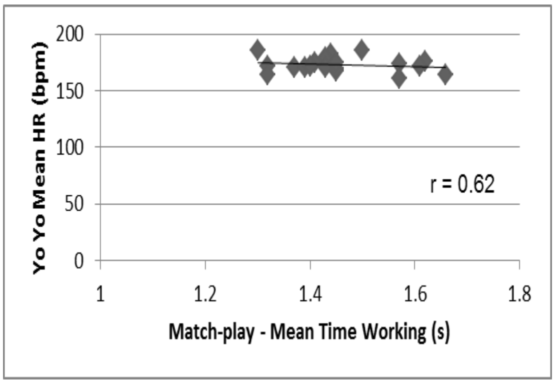

Figure 20, Relationship between Yo Yo Mean HR(bpm) and match-play working (s)

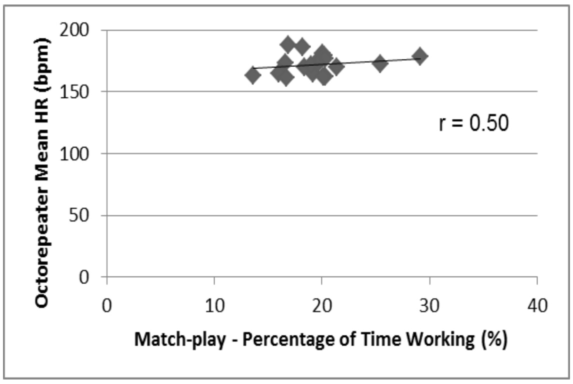

Figure 21 Relationship between Octorepeater Mean HR(bpm) and match-play working (%)

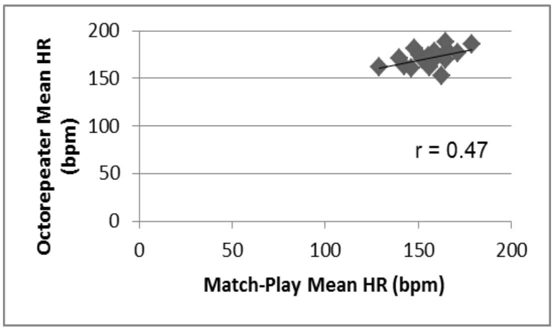

Figure 22, Relationship between Octorepeater Mean HR (bpm) and Match-play Mean HR (bpm)

Chapter Five: Discussion and Conclusion

The interpretation and discussion of results are divided into three sections as per the previous results section, focussing on the research questions.

Differences across the duration of a match that occur between Q1 and Q3, and also between Q2 and Q4 are important as umpires are officiating under the exact same conditions. A netball umpire officiates at the same end of the court (Chapter 1, Fig 2) for the duration of a match, whereas teams swap ends (goal posts) after each quarter. Therefore teams only play for the same goal post for two quarters of a match (Q1 and Q3, and then Q2 and Q4 at the opposite end). Umpires only officiate for each team whilst attacking for two quarters. The 'intensity' of a match may differ for these pairs of quarters dependent on the team skill equality and therefore there may be a biased amount of time spent at one end of the court and one umpire may work at a higher rate for that particular quarter. This then highlights the importance of any significant differences between Q1 and Q3, and then Q2 and Q4 as an umpire is officiating under the same conditions during these pairs of quarters.

Section One:

What are the physical, physiological and movement demands during match-play?

1. Physical Demands

Accumulated Player Load ™ (PL) is used as a measure of exertion or work-rate, and is useful to identify if netball umpires work-rate is consistent, decreases or increases across a match. Results from our study showed that for elite netball umpires there was a significant 5% decrease from Quarter (Q) 2 to Q4 for accumulated PL (total workload across a period of time), though this was only of small magnitude.

A difference in work-rate could either indicate if there was a drop off for the umpires due to fatigue or perhaps that it was the players that had a decreased work-rate and the umpires responded accordingly. As this was the first study to our knowledge that compared total PL across each quarter of a match in order to determine any significant changes, there was no specific research to compare our results too. However Chandler et al (2014) did utilise PL per minute as an indicator of physical demands for collegiate netball players and found that Centre's who covered the most distance during a match, also elicited a greater PL per minute. It was also found that elite netball players had a greater PL per minute during a match in comparison to lower standard netball players (Cormack, Smith, Mooney, Young, & O'Brien, 2014). This then may indicate that umpires who officiate higher level competitions work at a greater PL in order to keep up with the players.

Estimated Equivalent Distance (EED): The Catapult GPS system estimated an equivalent distance based on PL values. Distance travelled in each quarter ranged from 934 – 981m with a significant difference (p = .05; 5% or 47m decrease) between Q2 and Q4. As this variable is aligned with PL it also suggested either fatigue in the umpires, or a slower pace of game due to the players as the match progressed. The overall match EED of 3.84km was very similar to the only previous research on netball umpires who reported a distance of 3.85km (Otago et al., 1994). It was interesting to note that these distances were so similar considering the increase in player performance and longer periods of work (Fox et al., 2013), as well as the different methods used to calculate distance. Our current method was based on GPS values as discussed previously, however in 1994 the method was to use video footage to calculate distance based on the court dimensions. Data was only collected for one umpire during one match in 1994, and therefore may not be considered reliable due to the extremely small sample size. As no other netball research has reported any further distances travelled by umpires, nor is there any data available for basketball referees further comparisons for courts of this size are not possible.

There is however data available for the distances that netball players cover during a match, and these are far greater than an umpire. A Centre covers on average the most distance at 7.98km (over twice the distance of an umpire), whereas a Goal Keep, who only can move within one third of the court, covers 4.28km and a Goal Shoot covers 4.22 km (Davidson & Trewartha, 2008). All players cover nearly half a kilometre more than a netball umpire during a match, suggesting that players are much more active on the court in comparison to umpires, even when the ball is at the opposite end. As umpires cover much less distance than players, it suggested then that the same fitness training and fitness testing as players is likely to be less valid and that umpires should have individualised training and testing to meet their demands.

The decreased distance covered per quarter by the umpires from Q2 onwards was again suggestive that either the umpire or the players tire and slow, hence the umpires covered less ground. Although previous umpire research does not show the same decreasing pattern, the distance did decrease between Q1 (970m) to Q3 (850m) and Q2 (1500m) to Q4 (980m) (Otago et al., 1994). This key decrease between the quarters was similar to the differences that we found between the same quarters, which is a good indicator that the match does slow just before half time, and again before full time when either players or umpires are fatigued.

2. Physiological Demands

The trend for both mean HR and percentage of HRpeak for umpires was to decrease over a match. A small ES was shown for both variables with significant decreases from Q1 to both Q3 and Q4, and from Q2 to Q4. A basketball referee however, who officiates across a similar size court and jurisdiction (with the same two umpire format) showed a very consistent mean HR and percentage of HRpeak across a match (Leicht, 2008).

The drop off in HR at the end of the first half and the second half for netball umpires indicated a slower pace of game by the players, as the umpires had enough time for their HR to recover. The differences found between a netball and basketball umpire HR may indicate that elite netball players fatigue and slow down near the end of each match half, whereas basketball players maintained the same intensity throughout. This may be explained by the frequent rotation of players during a basketball match, therefore the players can maintain a higher intensity of play for a whole match in comparison to netball players.

Overall the mean HR for netball umpires (154.79 ± 12.43 bpm) was similar to a basketball referee at 150bpm (Leicht, 2008). In comparison the mean HR of a netball umpire was lower than a football referee 161bpm (Mallo et al., 2009) and 165bpm (Catterall, 1993) which also was expected as a netball court size is much smaller, with less high intensity long duration movements required.

Mallo et al (2009) also found little variance across the match with 162 bpm in the first half and 160 bpm in the second for football referees, which was similar to our netball umpires with an average HR of 156 bpm in the first, and 153 bpm in the second half. Though it was a very small difference, it did suggest that umpires in general may work at a slower pace in the second half of a match, with more time for recovery due to the lower mean HR.

HR intensity as a whole decreased across a match, with the lowest mean HR and percentage of HRpeak shown in Q4 (79.04 ± 7.76% and 152.63 ± 14.1 bpm). Basketball referee's also had the lowest mean HR and percentage of HRpeak in Q4 (78.3% and 149 bpm), though this was only a very small decrease from their highest recorded in Q2 (79% and 150.4 bpm) (Leicht, 2008). The similar findings suggested that the workload and intensity of umpires was similar between both sports, and therefore similar base aerobic training for netball umpires maybe adopted based on elite basketball referee programs.

The significant differences between Q1 and Q3 (p = .002), and Q2 and Q4 (p = .001) highlighted the changes in physiological demands for netball umpires when officiating under the same conditions, i.e. the same team defending and attacking at their end of the court. These differences as mentioned above indicated the slower pace of game nearing the end of each match half. However the magnitude of effect size was small for all HR differences and therefore it is questionable how meaningful these differences were when the overall percentage of HRpeak is low.

Though this decrease in HR indicates that umpires are not working to the same level as they progress through a game, it is most likely based on a slower pace or lower work-rate, possibly due to the pace of the game and a reaction to the players slowing. There is no data available for netball player intensity during each quarter so future research which took into consideration the HR for players alongside umpire HR would provide an interesting comparison and identify if this is explanation has merit.

If it were a case of the umpires slowing due to their fatigue we would have expected to see an increase in HR in order to keep up with the play, and HR recovery would take longer. It is likely therefore that based on the HR data alone, current umpire fitness level is adequate to keep up with the players and the level of match.

Umpires spent the most time (34.4 ± 16.01%) working at intensities in HR Zone 3 (75 – 85% HRpeak) during a 60min match. Due to the intermittent nature of this sport, both the high and low (rest-recovery) intensity movements are frequent and interspersed enough to maintain an average HR in this zone. As the umpires maintained their HR in the aerobic endurance zone (Otago et al., 1994), this emphasised that a solid aerobic fitness base was important to officiate at an elite level. The majority of time spent in this HR Zone was also expected as it relates to the mean percentage of HRpeak within each quarter (range 79 – 81%).

Overall during a match umpire intensity occurred most often within HR Zones 2 (25.27 ± 21.12%), 3 (34.41 ± 16.01%) and 4 (27.32 ± 19.34%), which meant that around 90% of time was spent between 60 – 93% of HRpeak. Very little time was spent at HR intensities lower or greater than this.

Previous umpire research showed that at an elite level only 12.5% of total time was spent in the 75 – 85% HR Zone, and 50.5% spent above 92% of HRpeak. These results differed quite substantially to our current findings of only 8% of time spent above 93% of HRpeak. They also found that 25% of time was spent with a HR below 75% of HRpeak (Otago et al., 1994) which was similar to our present findings (29%). The great amount of time spent in the highest HR Zone could suggest that umpires were not conditioned enough for the demands of the higher match play in 1994. Whereas results for the lower grade match showed that umpires were better conditioned, with 46.7% of time spent between 75 – 85% HRpeak, and 32.7% at 85 – 92%, and only 9% of time at over 92% HRpeak, which was very similar to our current findings. The greater percentage of time spent in the lower HR Zones during our present study suggested a higher fitness level or better conditioning for the demands in comparison to the early 1990’s. In later quarters in the match, the umpires spent less time working at higher intensities with a significant decrease in time spent in HR Zone 4 and 5 (Fig 10), whereas they spent longer durations at lower HR intensities (21 – 28%).

Direct comparison of these results to previous findings for netball players is hard due to the differing demands. A Centre spent most of their game active, though only 25% of their time is spent above 95% HRpeak. They spend 44% of time between 85 – 95%, 9% between 75 – 85% and 22% below 75% of HRpeak. Whereas a Goal Attack actually spent more time in a higher HR Zone (54% at greater than 95%), and minimal time in lower HR zones 6% at 75 – 85% and 0% at lower than 75%. (Woolford & Angrove, 1992). It should be noted that the player research is quite dated, so player results may be differ with today’s match demands.

3. Movement Demands

The movement variables analysed in this study were measured by frequency, mean time and percentage of time. . Previous studies did not analyse specific movements (Davidson & Trewartha, 2008; Loughran & O'Donoghue, 1999; Otago, 1983; Otago et al., 1994) with the exception of two papers Gasston & Simpson (2004) and Steel & Chad (1992). Therefore in some cases for our current results we combined movement types to provide a comparison.

Movement Frequency

Umpires performed far greater *rest-recovery* (1080.63 ± 131.9) movements than *work* (438.42 ±105.04) during matches. This frequent rest-recovery indicated that umpires have plenty of chance to recover from the higher intensity *work* movements. Umpires predominantly used *standing* (453.63 ± 38.4) for *rest-recovery* and this movement occurred 5% more frequently during Q2 than in Q3 suggesting that umpires did suffer from fatigue near the end of the first half. After the half time break, the umpires chose active *rest-recovery* more frequently, most likely due to feeling refreshed after a rest.

In comparison, in 1994 a netball umpire performed a quarter of the amount of *standing*, only 349 *rest-recovery* movements and 251 *work* movements (Otago et al., 1994). A much greater frequency of walking was observed for the duration of a match in 2012 (*M* = 625). Though Otago et al (1994) combined all walking types into one ‘walking’ category (*M* = 247), whereas for this study we split these into three – forwards, backwards and sideways.

Umpires in 2012 were seen to perform high intensity work movements (*M* = 399) more frequently than in 1994, (*M* = 251) and they also were ‘stationary’ on a more frequent occasion. The large difference in results between the two studies may not necessarily be due to the actual demands, but could be due to the different coding techniques used to analyse the data. A huge benefit in using newer technology like Sportscode Elite software means that all movements, even less than a second in duration were easily coded. Whereas the technique used in 1994 was to pause video footage and manually record each movement. It is possible that movements that were very short in duration (<1sec) may not have been included due to the mammoth task of coding in this way, therefore leading to the differing results between then and now.

Frequency of movement by netball players showed that a player in the Centre position performed the *walking forwards* movement (*M* = 367) most frequently, then standing (*M* = 293) for the duration of 4x 15 min quarters. The difference between a Centre and a Netball umpire is the area of the court that they cover, as a Centre runs from one end to the other following play, where as an umpire slows and stops when they reach the half-way point/ centre circle of the court as this is where their jurisdiction ends (Fig 2).This helps to explain the difference in the movement patterns used by umpires and players during match play. Overall an umpire *stands* and *sprints* more frequently than the players, though they use less frequent *jogging* and *walking* movements (Table 20).

Table 20. Comparison of Frequency of movement types for netball umpires and players.

		ST	W	WB	WS	J	R	SP	SS
Umpire	Paget, Spencer & Kilding	453	259	70	296	132		140	127
Umpire	Otago	102	247†			87		106	58
Centre	O'Lougran	291	323	130*		380	104		
	Fox, Spittle, Otago & Saunders	290				267	90	58	
	Davidson	213	298†			251	202	49	
	Steele and Chad	293	367	156	80			106	
Goal Attack	O'Loughran	279	276	122*					
	Fox, Spittle, Otago & Saunders	311				210	106	58	
	Steele and Chad	252	296	132	92	189	68	5	
Goal Defence	O'Loughran	319	301	121*		239	37		
	Fox, Spittle, Otago & Saunders	274				193	96	40	
	Steele and Chad	275	332	148	89	163	44	0	
Goal Shoot	Davidson	270	243†			52	51	43	
	Fox, Spittle, Otago & Saunders	234				56	68	51	
Goal Keep	Davidson	226	236†			38	25	10	
	Fox, Spittle, Otago & Saunders	159				58	27	5	
No Position∞	Gasston		212	184	64	196	56		392

ST = standing, W = walking, WB = walking backwards, WS = walking sideways, J = Jogging, R = running, SP = sprint, SS = Sidestep
**includes sideways walking*
†includes all walking types
♦running not walking
ɣ all lateral type movements
∞multiplied by 4 to create a whole match

The significant decrease in frequency of overall '*work*' that occurred from Q1 to Q3, and from Q2 to Q4 highlights the decreased work-rate by the umpires in the second half (M = 213.98) in comparison to the first half (M = 226.65). *Sidestepping* was the only individual *'work'* movement frequency with a significant difference ($p = .01$). Umpires performed this movement more frequently in Q1 (35.29 ±18.56) than in Q4 (28.36 ± 18.3). This could be as they used this movement a lot in the first quarter as they were fresher, and not yet fatigued, however by Q4 they were getting tired and swapped this out for a less vigorous type of movement, such as *walking sideways, forwards* or a slow *jog*. When taken into consideration alongside the physical and physiological data which indicated a reduced work-rate possibly due to the players and flow of the game, it may suggest that umpires are a little fatigued hence choosing a slower less intense activity.

Movement Mean Time

The average time spent performing each movement pattern within a match was an important variable as it indicated the length of time umpires worked at a specific intensity. The combination of the average time of high and low intensity movements and the overall percentage of time spent in each HR Zone provided an overall picture of the work and rest demands within a match.

Overall umpires spent longer mean duration of time in *rest-recovery* (2.37 ± 0.22s) movements compared to *work* (M = 1.84s) during a match, with a significant increase in the mean time *resting* during Q4 ($p < .001$). The significant ($p < .001$) increase in the average amount of time spent per *rest-recovery* period suggested the impact of fatigue later in the match as either umpires or players, or both needed longer ‘recovery’ time as the match went on. The effect size was medium between Q1 and Q2, and Q1 and Q4 which highlighted the fatigue as the umpires (or players) neared the end of the first half or the end of the match. The small effect size between Q1 and Q3 suggested that the longer half time break was enough recovery for the umpires (and players).

The longest durations of time were spent *standing* (4.4 ± 0.75s), with *walking forwards* the second longest (2.3 ± 0.52s) and least for *walking sideways* (1.33 ± 0.16s) and *backwards* (1.47 ± 0.30s). The wait for the play of the ball to return from the opposite end of the court may explain why longer durations were spent in the static standing position, with a plausible explanation that umpires also often strolled slowly forwards to the end of their jurisdiction while the play was at the opposite end which is why walking forwards is the next highest. All individual movements also had a significant increase from Q1 to later quarters, indicating that no specific *rest-recovery* movement was more prominent.

There were no significant variance found across all quarters for the mean amount of time spent *working*, although periods of time were short (1.82 – 1.86s). The lack of variance may indicate optimal fitness levels as there was no significant drop off which would indicate fatigue as the match went on. Based on this it suggested that the umpires were fit enough to keep up with the game, and the players’ fitness and it was the players that dictated the longer *rest-recovery* periods.

The mean time spent *jogging* (1.61 ± 0.26s) and *sidestepping* (1.21 ± 0.23s) were very short, whilst the mean time spent *sprinting* (2.76 ± 0.26s) was only marginally longer. The sprint movement was utilised when a fast change of direction of play had taken place, such as a goal had been scored, or an intercept with a very quick change of direction to the other end of the court. Whereas the *jogging* and *sidestepping* movements tended to take place as the umpire followed the ball play either along the side line or the base line.

With no umpire data to compare these results to, we can only look at the mean time spent performing similar movement patterns by Netball players, although with a big difference in the area of court each player can move in, the best positions to use would be a Centre who covers a full court and a Goal Attack and Goal Defence who cover 2/3 of a court, similar to the umpire. Umpires spent much longer durations of time *standing* during a match than these three positions and less time *walking forwards* (Fox et al., 2013; Loughran & O'Donoghue, 1999; Steele & Chad, 1992). This made sense as they were often stationary when the ball was at the opposite end of the court whereas players tended to mirror their opponents to get into an optimal position. Umpires also in general spent more time *sprinting* and less time *jogging* than players during a match. This increased *sprinting* was likely due to an umpires requirement to keep up with the ball play after a fast change of direction, where as players were only required to catch the ball and pass it on. *Jogging* seems to occur less for umpires as to follow the ball play either fast/ sprinting movements are required, or *rest-recovery* type movements are utilised when the ball is at either end of the court. Only a small amount of time spent *jogging*, most often as a transition into the *sprinting* movement.

Umpire data that was available for mean time was not relevant due to the size of the field or court, such as Rugby Union referees who performed each rest movement for 748 – 881s (Kraak et al., 2011).

Percentage of Time

The majority of time during a match was spent in *rest-recovery* movements (76.99 ± 5.94%), so with only 20% of time spent *working*, there was a huge amount of low intensity work that occurred during a match. It also emphasized the intermittent nature of the umpire demands and that they had a lot of recovery time with short bursts of intense work (*sprinting, sidestepping* and *turn to change direction*). The large amount of *standing* (49.27 ± 7.3%) during the match as mentioned previously also could indicate the amount of time the ball is at the opposite end of the court, while the umpire waits for it to return.

The significant 1.65% (r = .41, moderate ES) decrease in time spent *working* during a match from Q1 to Q4 again highlighted the decreased work-load later in the match by the umpires, either due to fatigue by the umpires or the players. There were no significant decreases for any particular individual movement type except for a 20% decrease for *sidestepping* from Q1 to Q4. *Sprinting* (9.71 ± 1.93%) was the *work* movement performed the most which emphasises the explanation of umpires frequently (M = 140) within a match needing to move from one end of their officiating area to the other at speed. Less than 10% of time was spent on all other *work* movements, which was expected as they are only used in short bursts and a lot less frequently.

Section Two:

Is there variance in the physical, physiological and movement demands between higher and lower ranked umpires?

1. Physical and Physiological Demands

There were no statistically significant differences between groups for accumulated Player Load™ (PL) and Estimated Equivalent Distance (EED), however Group Two overall had higher values for both variables. This suggests they performed a greater level of '*work*', either to keep up with the play or due to more 'energetic' movements overall leading to a higher work-rate and distance covered.

There were no significant differences found for mean HR between groups suggesting a similar level of fitness across the groups. Group One however did show a 2% greater percentage of HRpeak than Group Three, with a moderate magnitude of difference (d = .70). Indicating that Group One were working at a slightly higher intensity overall during a match based on their maximum HR. A significant difference was found between groups for the time spent in HR Zone 4 (85 – 94%), where Group One (34.11%) spent more time than Group Three (18.4%), again highlighting that Group One umpires worked at a higher intensity overall.

The general trend was for Group One to spend more time in higher HR Zones (3,4 and 5) than the other two groups, with Group Three spending much more time overall in Zone 2 (65-75%). This indicates that Group Three umpires worked at much lower intensities overall, which could either be due to the lower level of competition they were officiating or due to their high fitness levels in comparison to the players.

2. Movement Demands

Movement Frequency

The overall trend was that Group One umpires performed a significantly greater number of repetitions of *rest-recovery* during a match in comparison with Group Two (d = 1.41, large magnitude of effect) and Three (d = 0.88, medium magnitude of effect) umpires. Group One umpires also performed more *work* movements than the other two groups, although this was not significant. This is likely due to the need for Group One umpires to follow the pace of the game set by higher level players. Without specific research to confirm that higher level netball players work at a greater intensity and therefore rest more frequently than lower level players, we can only speculate based on research in Australian Football League (AFL) and Rugby League.

Research has looked into the differences between elite and sub-elite players for both these sports. Although a very different sport to netball, AFL found that elite players performed a greater number of high intensity movements during a match in comparison to sub-elite players, and that this number decreased for both groups from the first to the second half (Brewer, Dawson, Heasman, Stewart, & Cormack, 2010).

Whereas a comparison between match-play demands for elite and sub-elite Rugby League players showed that the frequency of high intensity movements decreased by the second half for the elite players, but not for the sub-elite. Elite players also worked at higher intensities during the first half, than the sub-elite (Sirotic, Coutts, Knowles, & Catterick, 2009). The similarities between the higher standard players/ umpires shows that match-play demands are much higher at this level in comparison to lower level matches.

Group One umpires performed *walking sideways* and *walking backwards* movements more than Group Two (r = .57 and r = .54 respectively, large magnitude of effect), which suggests a difference in movement technique whilst recovering. Choosing these movements indicates that the Group One umpires seem to consistently think about keeping their hips/ heads orientated towards the court and ball-play and could relate to a sign of experience and better positioning. Keeping the body orientated towards the ball play is a key performance indicator of experience and level (Netball New Zealand, personal communication, October 2012).

The *turn to change direction* movement was classified as turning to change direction at speed. Netball umpires have two main areas on the court where they require a change of direction, both at speed and after being stationary. This is on the Goal Line, when a goal has been shot, and the second most common area is when the umpire reaches the centre of the court and ways to keep their body positioned towards the ball and players, they perform this movement to change from a jog or sprint to walking backwards or sideways. This movement also takes place when there has been a change of possession on the court, and the flow of the game quickly changes direction. The umpires choose to either use this movement or they transition in to a *sidestep, walk sideways* then *forwards*.

The extensive use of the *turn to change direction* movement by Group One in comparison to the other two groups is also suggestive of a differing of technique by the higher level of umpire. The more experienced Group One umpires make the fast turn to ensure that they are always facing the play of the ball and are able to react to the next movement by the players.

Movement Time (Mean Time and Percentage of Time)

Group One spent less mean time and less total time (%) than Group Two (d = 1.09 and r = .43 respectively, both of moderate magnitude) and Group Three (large magnitude) performing overall *rest-recovery* movements. As Group One umpires generally had larger crowds, international media coverage and greater pressure, this could be a reason that these Group One umpires spent less time resting and more time moving (Downward & Jones, 2007)

It may also be attributed to the fitness levels, with faster recovery and therefore less time needed in a *rest-recovery* type movement, or a fast pace of game with less opportunity to rest.

The differences between groups for the mean time spent performing the individual *rest-recovery* movements may also be explained by the preferred choice of *rest-recovery* movement type by the individual umpires, although the significant differences may also be down to the experience or skill of the umpire. With longer periods of time as well as more time overall spent *walking sideways* and *walking backwards* by Group One umpires, this chosen movement may be purposely chosen so they keep their bodies and heads orientated towards the ball play as mentioned with the higher frequency of these same movements.

Group One umpires (3.79 ± 0.40s) also spent 25% and 23% respectively less mean time *standing* during a match than either Group Two (4.74 ± 0.52s, *d* = 2.05, a very large magnitude) or Three (4.66 ± 0.85s, *d* = 1.31, a large magnitude). Group One also spent 25% less time *standing* overall than Group Two (*d* = 1.78, large magnitude) and 16% less than Group Three (*d* = 1.06, moderate magnitude). This again may be due to the faster pace of game at the higher ANZC level, with faster turnaround of ball play umpires have less opportunity to stand in one spot and are required to *work* more often and for longer durations.

Group Three umpires spent 23% more mean time *jogging* than Group One and Two (*d* = 1.59, both large magnitudes), and 60% more time overall *jogging* than Group One (*d* = 1.03, large magnitude), which indicated a slower pace of game as they also spent less time *sprinting* (both mean time and percentage of time). These results for the lowest level Group indicated the lower level of competition they had control of and the slower speed of the game therefore requiring less *work* in comparison to the higher level umpire groups.

As *jog* and *sidestep* movements are less intensive than *sprinting*, the time spent performing each of these movements is likely due to umpire choice. Similar to the choice of *walking sideways* or *walking backwards* as a *rest-recovery* movement, the greater time spent *sidestepping* by Group One umpires indicates they chose to orientate their bodies towards the game more than the other two groups again indicating the role experience played.

As the courts are the same size for all groups, the greater time spent *sprinting* by Group One could also be due to the reaction to the players, i.e. the faster pace of game and change of directions. These results showing greater *work* by the higher level umpires are similar to the research on two levels of Rugby League referee, where the higher level of umpire performs more high intensity movements (sprinting) overall (Sirotic et al., 2009).

Section Three:

Does umpire performance in the Netball New Zealand (NNZ) specified fitness tests correlate with the movement, physical and physiological demands expressed during competition?

It was anticipated that the higher level umpires would be the 'fittest' and therefore their fitness test results would be higher than the other two umpire groups. However the large positive correlation ($r = .51$, $p = .02$) between umpire rank and Yo Yo Distance (m) suggested that the higher ranked (or lower performance level) umpires were more aerobically fit as they covered more distance during the Yo Yo Fitness Test. Although these results are in contradiction to our expectations, most of the higher ranked umpires were younger, male and more energetic, therefore more aerobically fit than the older more experienced Group One umpires.

As there was no correlation between umpire rank and the Octorepeater and Speed test indicates that these test results cannot be predicted by umpire level. As a large number of the correlations between fitness tests and match-play demands showed no significance ($p < .05$), it suggested that the current fitness test protocols may not provide strong validity for actual match-play activities and the demands placed on the umpires.

Yo Yo Test

The significant correlation between the distance covered in the Yo Yo fitness test and the percentage of time spent *jogging* during a match was of a large magnitude ($r = .51$). The further the umpire runs during the fitness test, or the more aerobically fit they are considered to be then the more time spent *jogging* during a match. As *jogging* is a key movement for the Yo Yo fitness test this indicated a relevance of the fitness test to match-play. The relevance of this for an entire match could be questioned though as only 5.4% of total time is spent *jogging* during a match.

Mallo et al (2007) found a relationship between the amount of high intensity activities (jogging and sprinting combined) and the 12-min run, which is considered a test of aerobic capacity, (Mallo et al., 2007) however similar to our results they found no significant relationship for sprinting alone and the results of their aerobic fitness test. In a similar study in 2009, a poor correlation between the amount of time spent performing high intensity activities and a new 150m high intensity Interval Test was also found (Mallo et al.,).

The percentage of time overall spent *sprinting* during the Yo Yo fitness Test generally means reaching a higher level result as the faster shuttles occur in the later stages of the test. The large significant negative relationship ($r = -.51$, $p = .04$) between this and match-play mean HR suggested that umpires who were more aerobically fit had lower mean HR's overall during match-play. As a lower mean HR can be an indicator of greater aerobic capacity (Mostert & Kesselring, 2002), this then suggested that this type of fitness is important for netball umpires and that the Yo Yo fitness test may be appropriate for assessing general aerobic capacity to ensure an umpire can keep up with match-play demands.

However as there were no significant correlations found between any of the actual fitness test measures (i.e. level reached) and the physical or physiological indices, the relationships between fitness test movements alone could not confirm the tests validity for predicting match-play fitness. They were purely suggestions based on what movements should occur during work during the fitness testing.

Despite the relationship suggesting that greater aerobic fitness equals working at a lower mean HR during a match, these results on their own are not conclusive that these fitness tests are valid for assessing the physiological demands placed on umpires during match-play.

The large correlation between the Yo Yo mean HR and the mean time (r = .62, p = .004) and percentage of overall time (r = .59, p = .01) spent *working* during match-play on the other hand suggested that umpires who had a higher HR during the aerobic fitness test work for longer periods during match-play. As the higher HR is suggestive of lower fitness or level of conditioning, it may portray the need for an umpire to *work* more to keep up with the play, if they are not as aerobically conditioned as they should be. These findings are similar to Mallo et al (2009) who found for football referee's, the greater their interval test mean HR the more high intensity exercise they performed during match-play.

Octorepeater

The moderate significant positive correlation between mean HR during the Octorepeater and during match-play (r = .47, p = .04) suggested that an umpire who has a higher heart rate when working anaerobically during the fitness test, has a higher HR during match-play. This indicated that match-play demands are similar to the anaerobic demands of the fitness test, and may provide an indicator of overall match intensity.

The large correlation between the Octorepeater mean HR and the percentage of time spent *working* during match-play (r = .50, p = .03), similar to the finding for the Yo Yo fitness test may suggest that the lower the anaerobic conditioning in the umpire, the more time spent working overall as the umpire attempts to keep up with the match-play. This again is similar to the findings of Mallo et al (2009) as discussed above for the relationship between the interval test mean HR and amount of high intensity exercise during match-play.

The moderate relationship between the frequency of *turn to change direction* in the Octorepeater and in match-play is suggestive that this turn during the fitness test is valid for the amount of 'turning' performed during match play. However as all other correlations between the same movement variable in match-play and the Octorepeater were poor, this point's to a low validity for the type of movements used and the length of time each are used for during the fitness test for what takes place during match-play.

Also despite a trend for a reduction in PL, EED, and the HR Variables (Chapter 4) from Q1 to Q4, this magnitude of reduction did not correlate with any of the fitness test measures. This suggested that despite being an umpire being ‘fitter’ it did not mean that their decrease in physiological indices during a match is greater than umpires who are considered to have a lower fitness level. There were also no relationships found between fitness test movements and the distance or work-rate variables this suggested that the fitness tests could not be used to predict the distances covered and PL work rate of the umpires during match-play.

Overall as no significant correlations were found between the fitness test results and match-play HR this indicates that the level of fitness achieved in the tests is not related to the intensity of work an umpire performs during match-play, and are therefore poor predictors of actual work-rates and match-play demands. Fitness tests that better mimic the amount of work performed during match play would provide more valid results

Practical Application

The results revealed an increased work-rate demand for higher level umpires (Group One), therefore it should be taken into consideration that these umpires require a greater level of fitness overall. Fitness testing should also take this into account and perhaps in order to qualify for Group One, a higher target in the fitness assessments should be met.

It should be taken into consideration the amount of time (total and mean) spent performing different movement types, and the minimal relationships between the current match-play and fitness test movement demands. There is a chance for a new anaerobic and aerobic fitness assessment to be utilised or designed in order to meet the specific demands place on elite netball umpires.

It also appears that current training undertaken by the umpires is adequate to keep conditioned in order to keep up with the current demands of play. However, perhaps these training regimes need to be documented each year and at the end of each season any increases in player performance needs to be taken into account, and umpire training and fitness levels reviewed.

Limitations

There were some limitations to this study, especially based on access to the highest level of umpires. It was not possible to attend all ANZC matches based on the cost of travelling to some of the smaller South Island towns. As umpiring is secondary to their main occupations, and the umpires were based all over NZ it was not possible to access all umpires at the same time for fitness testing, and in some cases an umpire could not attend at all.

The other major limitation was the number of GPS units available in order to test all umpires at the same time, so they had to be split into groups and share the units.

Delimitations

The findings from this study while applicable to elite New Zealand umpires may not be appropriate for community level umpires or umpires from other countries.

Future Research

Future research could look to provide information that the umpire is not only fit enough but skilled enough to read the play and be in the right position. This may be possible by looking at the decisions made at each critical point in the match, and the distance from each infringement.

Based on the findings in football, it is also prudent to look at the validity of any new fitness assessments in order assess if they are appropriate for the match-play demands placed on umpires.

Research into the players and umpire physiological demands during the same match could provide an insight into whether fatigue is first seen in the umpires or the players, and therefore if the fitness levels of the umpires is appropriate for the level of play.

Conclusion

In conclusion the overall demands of umpiring a netball match indicate that the majority (76.9%) of the match is spent performing *rest-recovery* movements, and that this is interspersed with short and sharp bursts of high intensity work. These shorter durations of *work* movements along with a high frequency also highlights the high intensity intermittent nature of umpire movement during a match, with longer periods of *rest-recovery* as the match progresses. The significant decrease in the frequency of *work* movements from Q1 through to Q4 also highlight the reduced work rate by umpires over the course of a match.

The combined physiological and physical data, of a lower mean HR, lower percentage of HRpeak, greater time spent in lower HR Zones (therefore less time spent in higher HR Zones), lower PL and lower EED in Q4 in comparison to Q1 and Q2, all again indicates the reduced work-rate of umpires later in the match.

Although PL and EED alone suggests that the umpires are fatiguing and not able to keep up with the play, the reduced HR suggests that the umpires are not needing to work as hard to keep up with the play, and therefore it is the players that are slowing and as a reaction the umpires are able to reduce their work rate. It is important to note that it is the umpire's job to react to the players on court and the speed of the match, therefore many of these findings may be due to the player's fitness levels as opposed to their own.

In comparison to the only other netball umpire research available very similar distances are covered during a match (Otago et al., 1994), however a much greater frequency of all movements is performed by umpires in 2012.

The higher level umpires work at higher intensities and for longer periods, most likely due to the higher level of competition and all the external pressures that are associated with it, such as media coverage, international appointments and crowds. This is similar to findings for AFL and Rugby League players where the elite players work at greater intensities during the match in comparison to the sub-elite players (Brewer et al., 2010; Sirotic et al., 2009). Netball umpires also chose different *rest-recovery* or *work* type movements dependent on the group they were part of, with the more experience Group One Umpires choosing to use the movements which keep their bodies orientated towards the ball more often than the other two squads.

A final point is that although fitness variables may indicate if the umpires can keep up with the match, and highlight any signs of fatigue it does not paint a full picture without an assessment of the decisions made during a match. An umpires' skill relies on their ability to keep up with the game and be in the right place at the right time, so this not only means fitness to keep working at the desired fitness level, but knowing where to be. Having the correct reaction or reading the play for any quick changes of direction, being in the right spot to see any incidents and making the correct calls, as well as making these decisions in split seconds so as not to impede on any advantage. This may be an opportunity for further research to extend these current findings of match-play demands and any variance between umpire groups.

In summary to provide an answer to Research Question Three,, does umpire performance in the NNZ specified fitness tests correlate with the movement, physical and physiological demands expressed during competition, the present findings showed that very few results provided strong enough relationships to quantify the validity of the current testing protocols. The relationships between fitness test HR and the work during match-play provides some indication that an umpire who is not as conditioned will struggle to keep up with match-play and therefore work for longer periods. However this provides a generalised validity for overall fitness, but not necessarily specific to umpire's physical and physiological match-play demands. The only further correlation which show some support to the validity of the current fitness tests are the relationship between the amount of turns in match-play and the Octorepeater. This suggests that a test with a similar number of turns to the Octorepeater is valid.

Lastly the relationship between Yo Yo distance and percentage of match-play jogging provides some validity, however as jogging is such a small part of the overall match, a better test could be utilised which mimics all movement types used.

Reference List

Bangsbo, J., Laia, F. M., & Krustrup, P. (2008). The Yo-Yo Intermittent Recovery Test: A Useful Tool for Evaluation of Physical Performance in Intermittent Sports. *Sports Medicine, 38*(1), 37-51.

Bloomfield, J., Polman, R., & O'Donoghue, P. (2004). The 'Bloomfield Movement Classification': Motion Analysis of Individual Players in Dynamic Movement Sports. *International Journal of Performance Analysis in Sport, 4*(2), 20-31. http://cpa.uwic.ac.uk/eijpas/.

Bloomfield, J., Polman, R., & O'Donoghue, P. (2007). Reliability of the Bloomfield Movement Classification. *International Journal of Performance Analysis in Sport, 7*(1), 20-27.

Brewer, C., Dawson, B., Heasman, J., Stewart, G., & Cormack, S. (2010). Movement pattern comparisons in elite (AFL) and sub-elite (WAFL) Australian football games using GPS. *Journal of Science and Medicine in Sport, 13*(6), 618-623. doi: http://dx.doi.org/10.1016/j.jsams.2010.01.005

Bruce, L., Farrow, D., Raynor, A., & May, E. (2009). Notation analysis of skill expertise differences in netball. *International Journal of Performance Analysis in Sport, 9*(2), 245-254. http://cpa.uwic.ac.uk/eijpas/.

Casajus, J. A., & Castagna, C. (2007). Aerobic fitness and field test performance in elite Spanish soccer referees of different ages. *Journal of Science and Medicine in Sport, 10*(6), 382-389. doi: 10.1016/j.jsams.2006.08.004

Castagna, C., Abt, G., & D'Ottavio, S. (2002). Relation between fitness tests and match performance in elite Italian soccer referees. *Journal of Strength & Conditioning Research, 16*(2), 231-235. journals.lww.com/nsca-scj

Castagna, C., & D'Ottavio, S. (2001). Effect of maximal aerobic power on match performance in elite soccer referees. *Journal of Strength & Conditioning Research, 15*(4), 420-425. journals.lww.com/nsca-scj.

Catterall, C. (1993). Analysis of the work rates and heart rates of association football referees. *British journal of sports medicine, 27*(3), 193. doi: 10.1136/bjsm.27.3.193

Chandler, P. T., Pinder, S. J., Curran, J. D., & Gabbett, T. J. (2014). Physical Demands of Training and Competition in Collegiate Netball Players. *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.), 28*(10), 2732-2737. doi: 10.1519/JSC.0000000000000486

Cormack, S. J., Smith, R. L., Mooney, M. M., Young, W. B., & O'Brien, B. J. (2014). Accelerometer Load as a Measure of Activity Profile in Different Standards of Netball Match Play. *International Journal of Sports Physiology & Performance, 9*(2), 283-291.

Coutts, A. J., & Duffield, R. (2010). Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of Science and Medicine in Sport, 13*(1), 133-135. doi: 10.1016/j.jsams.2008.09.015

da Silva, A. I. c., Perez, R. F., & Fernandes, L. z. C. u. (2007). Determining physical capacity and anthropometric profi le of soccer woman referee. *Fitness & Performance Journal (Online Edition), 6*(1), 45-52.

Davidson, A., & Trewartha, G. (2008). Understanding the Physiological Demands of Netball: a time-motion investigation. *International Journal of Performance Analysis in Sport, 8*(3), 1-17. http://cpa.uwic.ac.uk/eijpas/.

de Oliveira, M. C., Guerrero Santana, C. H., & de Barros Neto, T. b. L. (2008). Analysis of in-field displacement patterns and functional indexes of referees during the soccer match. . *Fitness & Performance Journal (Online Edition), 7*(1), 41-47.

Dogramac, S. N., Watsford, M. L., & Murphy, A. J. (2011). The reliability and validity of subjective notational analysis in comparison to global positioning system tracking to assess athlete movement patterns. *Journal of Strength and Conditioning Research, 25*(3), 852-859. doi: 10.1519/JSC.0b013e3181c69edd

Downward, P., & Jones, M. (2007). Effects of crowd size on referee decisions: Analysis of the FA Cup. *Journal of Sports Sciences, 25*(14), 1541-1545. doi: 10.1080/02640410701275193

Duffield, R., Reid, M., Baker, J., & Spratford, W. (2010). Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports. *Journal of Science and Medicine in Sport, 13*(5), 523-525. doi: 10.1016/j.jsams.2009.07.003

Duthie, Pyne, D. B., & Hooper. (2003). The reliability of video based time motion analysis. *Journal of Human Movement Studies, 44*(259 - 272).

Fox, A., Spittle, M., Otago, L., & Saunders, N. (2013). Activity profiles of the Australian female netball team players during international competition: Implications for training practice. *Journal of Sports Sciences, 31*(14), 1588-1595. doi: 10.1080/02640414.2013.792943

Gabbett, T. J., Kelley, J. N., & Sheppard, J. M. (2008). SPEED, CHANGE OF DIRECTION SPEED, AND REACTIVE AGILITY OF RUGBY LEAGUE PLAYERS. *Journal of Strength and Conditioning Research, 22*(1), 174-181. doi: R-20616 [pii] 10.1519/R-20616.1

Gasston, V., & Simpson, C. (2004). A netball specific fitness test. *International Journal of Performance Analysis in Sport, 4*(2), 82-96. http://cpa.uwic.ac.uk/eijpas/.

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. doi: http://dx.doi.org/10.1016/j.jsams.2013.01.007

Hale, S. L., & O'Donoghue, P. (2007). Addressing turning and direction changes when using the Bloomfield Movement Classification. *International Journal of Performance Analysis in Sport, 7*(3), 84-89. http://cpa.uwic.ac.uk/eijpas/.

Helsen, W., & Bultynck, J. B. (2004). Physical and perceptual-cognitive demands of top-class refereeing in association football. *Journal of Sports Sciences, 22*(2), 179-189. http://www.bases.org.uk/Home.

Hopkins, W. G., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Medicine & Science in Sports & Exercise, 41*(1), 3-12. doi: 10.1249/MSS.0b013e31818cb278

IFNA: Current World Rankings. (2012). Retrieved June 13, 2012, from http://www.netball.org/ifna.aspx?id=94

Jenkins, R. E., Morgan, L., & O'Donoghue, P. (2007). A case study into the effectiveness of computerised match analysis and motivational videos within the coaching of a league netball team. *International Journal of Performance Analysis in Sport, 7*(2), 59-80. http://cpa.uwic.ac.uk/eijpas/.

Kay, B., & Gill, N. (2003). Physical demands of elite Rugby League referees: Part one—time and motion analysis. *Journal of Science and Medicine in Sport, 6*(3), 339-342.

Kay, B., & Gill, N. D. (2003). Physical demands of elite Rugby League referees: Part one — time and motion analysis. *Journal of Science and Medicine in Sport, 6*(3), 339-342. doi: http://dx.doi.org/10.1016/S1440-2440(03)80027-0

Kay, B., & Gill, N. D. (2004). Physical demands of elite rugby league referees, part two: heart rate responses and implications for training and fitness testing. *Journal of Science & Medicine in Sport, 7*(2), 165-173. www.jsams.org/.

Kraak, W. J., Malan, D. D. J., & Van den Berg, P. H. (2011). Analysis of movement patterns and work-to-rest ratios for different panels of South African Rugby Union referees during matchrefereeing. *International Journal of Performance Analysis in Sport, 11*(2), 344-355. http://cpa.uwic.ac.uk/eijpas/.

Krustrup, P., & Bangsbo, J. (2001). Physiological demands of top-class soccer refereeing in relation to physical capacity: effect of intense intermittent exercise training. *Journal of Sports Sciences, 19*(11), 881-891. http://www.bases.org.uk/Home.

Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., . . . Bangsbo, J. (2003). The Yo-Yo Intermittent Recovery Test: Physiological Response, Reliability, and Validity. *Medicine & Science in Sports & Exercise, 35*(4), 697-705. www.acsm.org/.

Krustrup, P., Mohr, M., & Bangsbo, J. (2002). Activity profile and physiological demands of top-class soccer assistant refereeing in relation to training status. *Journal of Sports Sciences, 20*(11), 861-871. http://www.bases.org.uk/Home.

Krustrup, P., Mohr, M., Nybo, L., Majgaard Jensen, J., Jung Nielsen, J., & Bangsbo, J. (2006). The Yo-Yo IR2 Test: Physiological Response, Reliability, and Application to Elite Soccer. *Medicine & Science in Sports & Exercise, 38*(9), 1666-1673. www.acsm.org/.

Leicht, A. S. (2004). Cardiovascular stress on an elite basketball referee during national competition. *British journal of sports medicine, 38*(4), e10. doi: 10.1136/bjsm.2003.006908

Leicht, A. S. (2008). Physiological demands of basketball refereeing during international competition. *Journal of Science and Medicine in Sport, 11*(3), 357-360. doi: 10.1016/j.jsams.2007.05.006

Loughran, B. J., & O'Donoghue, P. (1999). Time-Motion Analysis of Work-Rate in Club Netball. *Journal of Human Movement Studies, 36*, 37-50.

MacLeod, H., Morris, J., Nevill, A., & Sunderland, C. (2009). The validity of a non-differential global positioning system for assessing player movement patterns in field hockey. *Journal of Sports Sciences, 27*(2), 121-128. http://www.bases.org.uk/Home.

Maddock, B. J. (2003). *Understanding positional demands and team-based performance of elite Australian netball: time motion and notational based analysis*. [Australia]; Australia: s.n.

Mallo, J., & Navarro, E. (2009). An√°lisis biomec√°nico aplicado a la evaluaci√≥n del rendimiento t√©cnico de los √°rbitros y √°rbitros asistentes de f√∫tbol. / Biomechanical analysis applied to the assessment of the technical performance in soccer referees and assistant referees. *Revista Kronos, 8*(15), 123-130.

Mallo, J., Navarro, E., Garcia-Aranda, J. M., Gilis, B., & Helsen, W. (2007). Activity profile of top-class association football referees in relation to performance in selected physical tests. *Journal of Sports Sciences, 25*(7), 805-813. http://www.bases.org.uk/Home.

Mallo, J., Navarro, E., Garcia-Aranda, J. M., & Helsen, W. (2009). Activity profile of top-class association football referees in relation to fitness-test performance and match standard. *Journal of Sports Sciences, 27*(1), 9-17. http://www.bases.org.uk/Home.

Martin, J., Smith, N. C., Tolfrey, K., & Jones, A. M. (2001). Activity analysis of English premiership rugby football union refereeing. *Ergonomics, 44*(12), 1069-1075. doi: 10.1080/00140130110098237

Mascarenhas, D. R. D., Collins, D., & Mortimer, P. (2005). Elite Refereeing Performance: Developing a Model for Sport Science Support. *Sport Psychologist, 19*(4), 364.

McLellan, C. P., Lovell, D. I., & Gass, G. C. (2011). Performance Analysis of Elite Rugby League Match Play using Global Positoning Systems. *Journal of Strength and Conditioning Research, 25*(6), 1703-1710. journals.lww.com/nsca-scj.

Montgomery, P. G., Pyne, D. B., & Minihan, C. L. (2010). The physical and physiological demands of basketball training and competition. *International Journal of Sports Physiology & Performance, 5*(1), 75-86. http://www.humankinetics.com/journals.

Mostert, S., & Kesselring, J. (2002). Effects of a short-term exercise training program on aerobic fitness, fatigue, health perception and activity level of subjects with multiple sclerosis. *Multiple Sclerosis, 8*(2), 161-168. doi: http://dx.doi.org/10.1191/1352458502ms779oa

O'Conner, D. (1994). Time Motion Analysis of Elite Touch Referees. *Sports Coach, 17*(2), 19 - 21.

O'Donoghue, P. (2007). Reliability Issues in Performance Analysis. *International Journal of Performance Analysis in Sport, 7*(1), 35-48. http://cpa.uwic.ac.uk/eijpas/.

O'Donoghue, P., Mayes, A., Edwards, K. M., & Garland, J. (2008). Performance Norms for British National Super League Netball. *International Journal of Sports Science & Coaching, 3*(4), 501-511. http://www.multi-science.co.uk/sports-science&coaching.htm.

Otago, L. (1983). A Game Analysis of the Activity Patterns of Netball Players. *Sports Coach, 7*(1), 24 - 28.

Otago, L., Riley, T., & Forrest, J. (1994). Movement patterns and energy requirements of netball umpires. . *Sports Coach, 17*(2), 10-14.

Ramsbottom, R., Brewer, J., & Williams, C. (1988). A progressive shuttle run test to estimate maximal oxygen uptake. *British journal of sports medicine, 22*(4), 141-144. doi: 10.1136/bjsm.22.4.141

Robinson, G., & O'Donoghue, P. (2008). A movement classification for the investigation of agility demands and injury risk in sport. *International Journal of Performance Analysis in Sport, 8*(1), 127-144. http://cpa.uwic.ac.uk/eijpas/.

Sirotic, A. C., Coutts, A. J., Knowles, H., & Catterick, C. (2009). A comparison of match demands between elite and semi-elite rugby league competition. *Journal of Sports Sciences, 27*(3), 203-211. doi: 10.1080/02640410802520802

Smart, D., Hopkins, W. G., Kenneth, Q. L., & Gill, N. D. (2011). The relationship between physical fitness and game behaviours in rugby union players. *European Journal of Sport Science*, 1-11. doi: 10.1080/17461391.2011.635812

Steele, J., & Chad, K. (1992). An Analysis of the Movement Patterns of Netball Players during Matchplay: Implications for designing training programs. *Sports Coach, 15*(1), 21-28.

Steele, J. R., & Chad, K. E. (1991). Relationship between movement patterns performed in match play and in training by skilled netball players. *Journal of Human Movement Studies, 20*, 249-278.

Sunderland, C., Taylor, E., Pearce, E., & Spice, C. (2011). Activity profile and physical demands of male field hockey umpires in international matches. *European Journal of Sport Science, 11*(6), 411-417. www.ecss.mobi.

Thomas, A., Dawson, B., & Goodman, C. (2006). The Yo-Yo test: reliability and association with a 20-m run and VO2max. *International Journal of Sports Physiology & Performance, 1*(2), 137-149.

Varley, M. C., Fairweather, I. H., & Aughey, R. J. (2012). Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion. *Journal of Sports Sciences, 30*(2), 121-127. doi: 10.1080/02640414.2011.627941

Weston, M., Castagna, C., Helsen, W., & Impellizzeri, F. (2009). Relationships among field-test measures and physical match performance in elite-standard soccer referees. *Journal of Sports Sciences, 27*(11), 1177-1184. http://www.bases.org.uk/Home.

Weston, M., Castagna, C., Impellizzeri, F. M., Rampinini, E., & Abt, G. (2007). Analysis of physical match performance in English Premier League soccer referees with particular reference to first half and player work rates. *Journal of Science & Medicine in Sport, 10*(6), 390-397. www.jsams.org/.

Weston, M., Castagna, C., Impellizzeri, F. M., Rampinini, E., & Breivik, S. (2010). Ageing and physical match performance in English Premier League soccer referees. *Journal of Science & Medicine in Sport, 13*(1), 96-100.

Weston, M., Drust, B., Atkinson, G., & Gregson, W. (2011). Variability of Soccer Referees' Match Performances. *International Journal of Sports Medicine, 32*(3), 190-194.

Weston, M., Siegler, J., Bahnert, A., McBrien, J., & Lovell, R. (2014). The application of differential ratings of perceived exertion to Australian Football League matches. *Journal of Science and Medicine in Sport*(0). doi: http://dx.doi.org/10.1016/j.jsams.2014.09.001

Woolford, S., & Angrove, M. (1992). Game Intensities in Elite Level Netball: Position Specific Trends. *Sports Coach, 15*(2), 28 - 32.

Young, W., Hepner, J., & Robbins, D. (2012). Movement Demands in Australian Rules Football as Indicators of Muscle Damage. *Journal of Strength & Conditioning Research, 26*(2), 492-496. doi: 10.1519/JSC.0b013e318225a1c4

Glossary

Elite:	Any participant at a regional, national or international standard. This is considered a high level of competition.
Club/ Recreational:	Any participant at a local competition that completes minimal or no training. This is considered a low level of competition.
Match:	Also known as a game
Umpire:	An official who ensures a match is played fairly and any rules broken are penalised, may also be known as a referee.
Invasion Ball Sports:	Any ball sport where the aim is to invade your opposition's territory and score points.
Physiological data:	Speed, distance, acceleration and deceleration, heart rate (HR).
Movement Pattern data:	Each study determined their own specific data which commonly included movements such as: sprinting, running, jogging, walking, standing, side stepping, changing direction and shuffling.
Physiological analysis:	Calculating total, mean, peak and percentage of duration for each physiological data type.
Movement Pattern analysis:	The use of video and audio recording to calculate the frequency and duration for each type of movement. Computer software may or may not be used to assist.
Intensity:	There are two types of intensity:

a) *Heart rate intensity*

Heart rate zones are calculated as a percentage of maximum heart rate and are categorised into four or five zones ranging from low to very high intensity.

b) *Movement pattern intensity*

Movement types are classified into work and rest-recovery categories. Each definition is specific per study, but generally work consists of sprinting, running and shuffling and rest-recovery consists of jogging, walking and standing.

Estimated Equivalent Distance:	this is the approximate jogging distance that would create the PL value. GPS units are unable to triangulate with the satellites when used indoor. Therefore to determine the actual tracked distance the Catapult Sports Sprint software used a formula that estimated an equivalent distance based on player load for indoor netball use.
Period:	time periods were created by inputing a start and finish time for each period. Periods were used to edit data for analysis. This study used quarters (15mins per quarter) and whole match (60mins).
Player Load™:	this was developed by Catapult and the Australian Institute of Sport to measure exertion or work rate based on the accelerometer data from the GPS units. Player Load™ (work rate) is defined as the measured acceleration in three planes, 1) coronal plane (left-right), 2) sagittal plane (forwards-backwards) and 3) vertical plane (up-down). It is not dependant on distance covered and therefore is a valid measure of workload for indoor sports mode (where satellite access is unavailable to measure actual distances) and also for non-running activities. There is a strong correlation between Player Load (PL) and distance covered when the athlete's main activity is running (Catapault Sports, Victoria, Australia).
HRpeak:	Individual maximum HR was recorded as the highest HR achieved during fitness testing (Yo Yo Intermittent Recovery Test Level1 or Octorepeater).
Heart Rate Zones:	These were custom HR zones calculated from the percentage of the peak heart rate (HRpeak) as determined by the pre and post-season Fitness Testing for each umpire. Heart rate was categorised into five zones so that the distribution of exertion can be determined (Chapter 3, Table 7).

Appendix One: Participation information and consent form

Participant Information Sheet

Project Title:

Development of a performance analysis model for high performance netball umpires

Why is this important?

Performance of referees/umpires in elite sport (i.e. soccer, rugby union, rugby league, field hockey and basketball) has been widely investigated. Fitness/aerobic testing performance has been compared to match day performance measures, including speed, distance covered and physiological demands. To date no such research has been conducted on netball umpires. This study aims to assess sports specific/functional movement patterns and physiological demands of high performance netball umpires on match days and compare this with the current fitness tests utilised by Netball New Zealand to determine if the tests are appropriate. Collection of this information will help improve selection, testing and training for elite level netball umpires.

What is required from me?

We need to analyse the games you umpire and your performance during the Netball New Zealand fitness testing protocols currently used for assessing all high performance umpires in NZ. There will be no additional demands placed on you over and above the normal match day requirements. For the testing days, proper warm ups, practice trials and protocol explanations will be completed before testing to ensure all participants are comfortable with the procedure, to minimize risk of injury and ensure standardization.

How will the data be collected?

During each match:
You will be filmed for the duration of the game.
Movement patterns will be analysed post game, using Sports Code Elite. Movements will include standing, jogging, sprinting, lateral movements and turning. A minimum of 2 matches per umpire will be filmed and any of the matches over the ANZC season may be targeted – confirmation will be made as soon as we are aware of who will be at what match.
On match days, you will be required to wear a GPS unit and a Heart Rate strap.
The GPS unit sits just above and centered between the shoulder blades and is quite a small unit. A lightweight minimax undergarment is worn comfortably over any underwear but under outerwear clothing and the GPS unit sits in a pouch on the back.
A soft Heart Rate strap is worn under clothing and sits next to the skin just below the sternum. Both are comfortable to wear and have been shown not to impact on performance in both players and umpires. The data collected will include heart rate intensities, acceleration, deceleration and distances covered.

Fitness Testing:
You may be filmed during testing. For the duration of each test you will be required to wear a GPS unit and Heart Rate strap as per above. Both the Yo Yo Intermittent Recovery Test (Level 1) and the 5, 10, 20m test will be performed. These tests will take place at your training camps or workshops throughout 2012.

Will the information collected remain confidential?

Yes, all information collected will be confidential with only the researcher and supervisors having access to names and the relative data. All information will be stored safely to ensure full privacy and once all data is collected, names will be transferred to codes so that it may be used in reports or further analysis of the data.

Will I get a copy of my results?

All information will be collected on behalf of Netball New Zealand, and a copy of the report including your results will be available when Netball New Zealand releases the report.

Whom do I contact for further information about this research?

Research Contact Details:

Natasha Paget
c/ Sport Performance Research Institute New Zealand
Auckland University of Technology
Private Bag 92006
Auckland, New Zealand 1142
natasha.paget@aut.ac.nz

Appendix Two: Consent Form

Consent Form	

Project title: ***Development of a performance analysis model for high performance netball umpires***

Project Organiser: ***Netball New Zealand***

Researcher: ***Natasha Paget***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 27 March 2012.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance, or any infection.
- ○ I agree to take part in this research which involves collecting information on movement and intensity of effort.
- ○ I understand that I will have access to a copy of the Netball New Zealand report when Netball New Zealand releases this to each umpire involved in the research.
- ○ I agree to Auckland University of Technology keeping confidential records of my de-identified data and that this may be used for statistical analysis in the above research project.

Please note that the analysis of this data, once it is de-identified, may be used as part of research for the above researchers qualification and that the Auckland University of Technology will hold on to the statistical data for a six (6) year period of time.

Participants signature:

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Participants name:

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Participants Contact Details (if appropriate):

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Note: The Participant should retain a copy of this form.