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THE PHYSICAL, PHYSIOLOGICAL AND PERFORMANCE CHARACTERISTICS OF ENGLISH YOUTH TEAM HANDBALL PLAYERS

This thesis is submitted in accordance with the requirements of the University of Chester for the degree of Doctor of Philosophy

Samantha Moss

July 2014

Summary

STUDY 1 (CHAPTER 3)

INTRODUCTION: In order to maximise the potential for success, developing nations need to produce superior systems to identify and develop talent, which requires comprehensive and up-to-date values on elite players. This study examined the anthropometric and physical characteristics of youth female team handball players (16.07 ± 1.30 y) in non-elite (*n*= 47), elite (*n*= 37) and top-elite players (*n*= 29). **METHODS:** Anthropometric profiling included sum of eight skinfolds, body mass, stature, girths, breadths and somatotype. Performance tests included 20 m sprint, counter movement jump, throwing velocity, repeated shuttle sprint and jump ability test, and Yo-Yo Intermittent Recovery Test Level 1. **RESULTS:** Youth top-elite players had greater body mass, lean mass, stature, limb girths and breadths than elite and non-elite players, while only stature and flexed arm were higher in elite compared to non-elite players (all $P < 0.05$). Sum of skinfolds and waist-to-hip ratio were similar between groups ($P > 0.05$). Top-elite performed better in most performance tests compared to both elite and non-elite players ($P < 0.05$), although maximal and repeated10 m sprints were similar between standard ($P > 0.05$). Elite outperformed non-elite players in throwing velocity only. **CONCLUSIONS:** Findings reveal that non-elite players compare unfavourably to top-elite international European players in many anthropometric and performance characteristics, and differ in few characteristics compared to elite European club team players. This study is useful for emerging team handball nations in improving talent identification processes.

STUDY 2 (CHAPTER 4)

INTRODUCTION: Detailed analysis of demands during match play is an essential requirement for the development of both optimal training practices and match simulations. This study aimed to provide a comprehensive analysis of team handball match play in youth English U18 Men's National League players through the assessment of player movement demands, technical actions and heart rate during match play. Secondly, the impact of team handball competition on fatigue during and after matches was also investigated. **METHODS:** Video analysis was used to monitor the movement demands and technical actions of 22 players (16.23 ± 0.92 y) during competitive team handball matches (2 x 20 min halves) from the English Youth National League. Movement categories included standing, walking, jogging striding, sprinting, backwards movement, sideways low-intensity movement and sideways high-intensity movement. Technical actions included shots, body contact, jumps, and technical errors in attack and defence. Physiological and neuromuscular responses were also performed in 21 players (age: 16.08 ± 0.72 y, stature: 180.06 ± 8.75 cm, body mass: 72.24 ± 9.68 kg), who were tested for physical performance measures (20 m sprint, counter-movement jump, throwing velocity) and blood lactate at baseline, half-time and full-time. Heart rate was also monitored continuously during matches. **RESULTS:** Total playing time was 36:24 ± 4:36 min, with players spending 94.24 ± 3.6% and 3.93 ± 0.82% of total time in low and high-intensity activity, respectively. Standing (38.15 ± 5.64%) and walking (21.99 ± 6.84%) accounted for the most time, while players sprinted for 0.92 ± 1.51% of total time. Most prevalent technical actions were shots (7.0 ± 5.0), body contact (15.5 ± 3.3), and jumps (15.50 ± 9.0). Average heart rate was 178 ± 13 $b \cdot min^{-1}$ (88.3 ± 4.9% HR_{max}). There were no differences in the time spent in either high- or low-intensity activity or heart rate over the course of the match ($P > 0.05$). However, total activity changes (165 ± 23 *cf.* 133 ± 29, $P < 0.001$) and total body contact (11.5 ± 10.3 *cf.* 5.5 ± 3.0, $P < 0.001$) decreased from the first to

the second half. Neuromuscular performance and blood lactate concentration was unchanged between halves (all $P > 0.05$). **CONCLUSIONS:** Despite predominance for low-intensity movements, high average heart rates highlight the large physiological demand imposed by other activities during matches. While high-intensity running was maintained, English players underwent decrements in body contact in the second half of matches. However, match demands did not compromise neuromuscular function during sprinting, jumping or throwing. Findings revealed notable differences to elite standard match analysis, relating to a lower frequency of sprints and activity changes in English players. This data exposes potential weaknesses in the English game and highlights the need to develop training practices that mimic the demands of elite competition. Specific conditioning to improve repeated high-intensity running capacity with frequent changes in speed is warranted.

STUDY 3 (CHAPTER 5)

INTRODUCTION: When exposed to intensified competition or training, elite team handball players experience decrements in neuromuscular function, while mood disturbances are observed as training load increases. Responses of non-elite players might warrant different approaches to player management and support processes. The aim of this study was to investigate neuromuscular fatigue and well-being of English handball players during a training camp and an international tournament. **METHODS:** Players were monitored for three days during the training camp (n= 9) and five days during the tournament (n= 14). Neuromuscular responses were measured using maximal 10 m sprint and counter-movement jump (CMJ). Player well-being was monitored daily using a questionnaire. Player match load was assessed by recoding heart rate (HR) and session rating of perceived exertion (sRPE). **RESULTS:** Players' 10 m sprint performance did not change during the training camp (1.89 ± 0.1 *cf.* 1.96 ±

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0.1 s, P = 0.09; 3.7%) but did during the tournament (1.84 ± 0.07 *cf.* 1.98 ± 0.12 s, P < 0.001; 8.03%). While there were reductions in CMJ flight time during the camp (0.54 ± 0.33 s *cf.* 0.51 ± 0.3 s, P = 0.008; 5%), values were unchanged during the tournament (P > 0.05).The greatest decreases were found for well-being in both the tournament (20.08 ± 1.98 *cf.* 17.83 ± 1.7, P = 0.008; 11%) and training camp (18.8 ± 2.6 AU cf. 16.56 ± 3.4 AU, P < 0.05; 11%). **CONCLUSIONS:** Performance decrements and decreased well-being were indicative of insufficient recovery of the neuromuscular system after intense match play. These findings can be used to inform practices that optimise recovery through appropriate player selection and interchange strategies, as well as ensuring the provision of adequate training stimuli to better prepare players for limited recovery during competition.

STUDY 4 (CHAPTER 6)

INTRODUCTION: Team handball players evidence fatigue-induced decrements in high-intensity activity from the first to second half of matches. Effective management of player work and rest periods during matches could help to minimise physiological loading and better maintain performance. This study aimed to establish the effect of two different interchange strategies on performance and pacing strategy during a simulated team-sports protocol. **METHODS:** Eight outfield youth male team handball players (age: 16.1 ± 1.0 y, stature: 1.82 ± 0.11 m, body mass: 69.3 ± 6.6 kg) completed two conditions of a team sport simulation. LONG comprised 3 x 13:00 min periods of work, separated by 8:00 min rest between activity periods. SHORT comprised 5 x 7:48 min periods of activity, separated by 3:45 min rest between work periods. Absolute work time (39:00 min) and rest (16:00 min) periods were the same for both conditions. Participants were tested for 20 m sprint, counter-

movement jump and throwing performance during each condition, with heart rate being monitored continuously. Post-condition measures included Repeated Shuttle Sprint and Jump Ability, session rating of perceived exertion, blood lactate and blood glucose. **RESULTS:** Sprint time deteriorated progressively throughout the simulation (P = 0.005), but overall faster sprint performance was apparent in SHORT (3.87 ± 0.27 s) rather than LONG (3.97 ± 0.24 s, P = 0.03) by a 'likely small' difference. Throwing velocity revealed a 'likely small' difference that was indicative of better performance in SHORT (70.02 ± 7.40 $km{\cdot}h^{-1}$) compared to LONG (69.04 ± 5.57 $km{\cdot}h^{-1}$, P > 0.05). There were no differences in throwing accuracy or counter-movement jump performance (P > 0.05). Practically meaningful higher average heart rate (166 ± 8 $b{\cdot}min^{-1}$ *cf.* 169 ± 9 $b{\cdot}min^{-1}$) and summated heart rate (150 ± 15 *cf.* AU 157 ± 21) were apparent in SHORT compared to LONG by a 'likely small' difference (P > 0.05). Post-condition measures showed that SHORT resulted in 'most likely moderate' lower sRPE (224 ± 45 AU *cf.* 282 ± 35 AU, P = 0.001), in addition to 'most likely moderate' higher blood glucose (6.06 ± 0.69 $mmol{\cdot}l^{-1}$ *cf.* 4.98 ± 1.10 $mmol{\cdot}l^{-1}$ P = 0.03) compared to LONG. However, there were no differences in blood lactate (P > 0.05) between conditions. Repeated shuttle sprint running performance was also better preserved after SHORT work and rest periods, with 'moderate' decreases in 10 m and 25 m sprint times (P < 0.05). **CONCLUSIONS:** Collectively, these findings suggest that interchange strategies using SHORT as oppose to LONG periods of work and rest result in overall lower physiological load that leads to improved fatigue resistance and a better preservation of high-intensity movements throughout a match. This information could prove valuable to maximise player performance both during a match and a tournament where multiple matches are played consecutively.

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List of abbreviations

% HR_{max}	percentage maximum heart rate
20-MST	20 m multi-stage fitness test
$30\text{-}15_{IFT}$	30-15 intermittent test
ANOVA	analysis of variance
ANCOVA	analysis of covariance
ATP	adenosine triphosphate
B	beginning
BLa	blood lactate
BM	body mass
cf.	compare
CL	confidence limits
CMJ	countermovement jump
CV	coefficient of variation
E	elite (chapter 3)
E	end (chapter 6)
EHA	England Handball Association
ES	effect size
Glu	blood glucose
HR	heart rate
HR_{max}	maximum heart rate
IQR	interquartile range
M	middle

MVC	maximal voluntary contraction
NE	non-elite
PASW	predictive analysis software
POMS	profile of mood states
r	pearson product-moment correlation
R^2	coefficient of determination
RESTQ-SPORT	recovery and stress questionnaire in sport
RPE	rating of perceived exertion
RM	repetition maximum
RSSJA	repeated shuttle sprint and jump ability
SD	standard deviation
sRPE	session rating of perceived exertion
TE	top-elite
TMA	time-motion analysis
$\dot{V}O_2$	oxygen uptake
$\dot{V}O_{2\max}$	maximal oxygen uptake
Yo-Yo IR1	Yo-Yo intermittent recovery test level 1
Yo-Yo IR2	Yo-Yo intermittent recovery test level
WB	well-being

CHAPTER 1

INTRODUCTION

1.1 An introduction to team handball

Team handball is an intermittent team sport played between two teams of seven players, including six outfield players and one goalkeeper. The popularity of team handball has continued to develop since the 1960s, being played at amateur, semi-professional and professional standards, and gaining Olympic status in 1972 (Ziv & Lidor, 2009). The International Handball Federation (IHF) report that ~19 million players from 795,000 teams are currently listed worldwide (IHF, 2009). Playing positions are broadly classified as goalkeeper, first line players, and second line players. Players who carry out activities during the first line of attack are wing and pivot players, with backs and centre-backs making up the second line players. Match play requires teams to alternate between phases of attack and defence, whereby the objective of the attack is to score a goal, while the defence aim to turn over the ball and prevent the opposition from scoring (*Š*ibila *et al*., 2004). Official rules from the IHF (2010) state that matches comprise two 30 minute halves for adults, with a fifteen minute (or less) interval between halves. Youth players aged 12 - 16 years play two 25 minute halves, while players aged 8 - 12 years play two 20 minute halves, although differences between national federations are apparent. Each team is also permitted one x 1 minute "time-out" for each half. Coaches are permitted unlimited substitutions throughout a match, and it is therefore unusual for a player to compete for the entire match duration (Luig *et al*., 2008; Ronglan *et al*., 2006). Before 2002, rules allowed twelve players per team, who were permitted to interchange with another player at any moment during the match, providing only seven players from a team were on the court at any one time. However, this has since been extended to fourteen players per team, enabling increased intensity of play and more flexible rest periods for players. Increased intensity of play has also occurred due to an additional rule change in 2002, stating that after a goal has been scored, the referee can restart match-play as soon as the attacking team has returned the ball to the centre line (Ronglan *et al*., 2006).

Scientific investigation into the demands imposed on players during team handball match play is scarce, although some recent studies are available in elite adults (Michalsik *et al*., 2013a; 2013b; Póvoas *et al*., 2012) and youth players (Chelly *et al*., 2011; Souhail *et al*., 2010). Of particular note is the lack of detailed understanding regarding competitive match play at the youth level, for which results have been based on friendly matches, with players competing in full matches without substitutions. Without up-to-date knowledge of the demands placed on players during competitive matches, training practices for match preparation might be less than optimal when attempting to imitate or overload the physiological systems (Duthie *et al*., 2003; Pers *et al*., 2002; Deutsch *et al*., 1998;).

In line with the highly demanding nature of team handball, the small amount of available literature suggests that players undergo match-related fatigue, manifested by an inability to maintain high-intensity movement activity during the second half of matches (Michalsik *et al*., 2013a, 2013b; Póvoas *et al*., 2012). The demands of team handball can also lead to prolonged fatigue evidenced by decrements in neuromuscular function after simulations (Thorlund *et al*., 2008; Singh *et al*., 2010), which might be exacerbated during multiple training sessions and matches (Ronglan *et al*., 2006). However, the impact of congested schedules on match performances is currently poorly understood. Assessing the extent to which neuromuscular function is compromised after matches, during tournaments and training camps could inform effective player management via recovery and interchange strategies. Given the allowance of unlimited interchanges during matches, this method could prove particularly useful to minimise fatigue and enhance performance during extended periods of competition and training (Karcher & Buchheit, 2014).

1.2 Physical and physiological characteristics of team handball players

Success in team handball at an elite standard is dependent on numerous external and internal factors, comprising anthropometric characteristics, physical capacity, technical and tactical skills, as well as psychological factors (Ronglan *et al*., 2006; Schoj *et al*., 2002). However, despite the popularity of team handball, particularly in Europe, detailed analysis of the essential characteristics needed for elite performance are not well researched.

Investigations into the characteristics of elite team handball players have tended to offer a monodisciplinary approach, which has been criticised pertaining to omission of other essential attributes needed for success (Mussu*c*a *et al*., 2014). The most prominently researched area relates to anthropometric characteristics, showing a tendency for elite players to have high statures and body mass (Rannou *et al*., 2001; Gorostiaga *et al*., 2004), alongside well-developed musculature or lean mass (Milanese *et al*., 2011). However, there is a lack of detailed analysis concerning youth players, particularly in females. Characteristics relating to performance have been identified from analysis of match play, highlighting that players are required to have a well-developed aerobic capacity, alongside the ability to exert force and power when sprinting, jumping, throwing, and changing direction at speed (P*ó*voas *et al*., 2012; Ronglan *et al*., 2006). However, very few studies have provided detailed analysis of player performance within a wide range of tests, thus making it problematic to establish attainable standards. A deeper understanding into the measureable attributes of team handball players, such as anthropometric and performance characteristics could be important to guide talent identification standards. Moreover, tracking players from youth to adult competition could provide important information on long-term athlete development processes and help to inform how players should be selected throughout their handball careers. Furthermore, through the establishment of standards on the key characteristics of elite standard players, training efforts can be focused accordingly.

1.3 English team handball players

Of specific interest is the distinct lack of data published on English team handball players. In fact, only one study (Hasan *et al*., 2007) to the author's knowledge studied English players, with their data being used as a reference to compare against teams competing in the Asian Team Handball Championships. This highlights a dearth of information on all aspects of scientific player support processes in this nation of team handball players, making it extremely difficult to use evidence-based approaches to aid the development of training and overall performance. The lack of research in English players does not correspond to the increased popularity of the sport in recent years, which has been largely attributed to the positive impact of the London Olympic Games, whereby team Great Britain received automatic home-nation qualification. Data from the England Handball Association (EHA, personal correspondence) shows that registered club members (>16 y) rose 37% in 2011 - 12 (680 members) and 96% in 2012 - 13 (1336 members) from 2010-11 season (493 members). This corresponds to a 13% increase in the number of affiliated clubs (2010 = 48; 2012 = 77 pre-Olympics; 2013= 87 post-Olympics). At youth level, the number of schools competing in the flagship National School Cup has increased, with the greatest increases observed in the U15 male and female age group (2011 – 12 = 79 teams; 2012 – 13 = 117 teams; 48% increase). Although this evidence bodes well for the future of team handball in England, continued development and improvement in the standard of performance requires the adoption of evidence-based approaches through pertinent research questions and appropriate dissemination of information to correct personal. Using this information, it is hoped that informed decisions can be made to execute best training and competition practices for the new generation of team handball players in England.

1.4 Aims of the current research

The main objective of this thesis was to investigate the physical, physiological and performance characteristics of English team handball players in order to develop effective strategies to improve performance.

Information on the essential characteristics for successful team handball performance is valuable to coaches and practitioners working with developing nations, where there are a limited number of athletes to select from and the sport is not well established (Mohamed *et al*., 2009). Therefore, to maximise the potential for success, it is important for such nations to develop superior systems to identify and develop talent, which requires comprehensive and up-to-date physical data on elite players (Carter *et al*., 2005). Therefore, the aim of Chapter 3 was to examine the anthropometric and physical characteristics of youth female team handball players from Great Britain in comparison to European elite and top-elite players.

Detailed analysis of demands during match play is an essential requirement for the development of optimal training practices (Michalsik & Bangsbo, 2002). Through gaining a greater understanding of the relative contribution of intensity, movement patterns, and technical actions performed during matches, coaches can establish specific training practices that imitate or overload the physiological systems (Duthie *et al*., 2003; Pers *et al*., 2002; Deutsch *et al*., 1998). As the demands imposed on English youth players during competition is unknown, analysis could elucidate key areas for development and aid with progression of the English game. Study 2 (Chapter 4) aimed to analyse team handball match play in youth U18 Men's National League players through the assessment of player movement demands, technical actions and heart rate during match play. Secondly, the impact of team handball competition on fatigue during and immediately after matches was also investigated.

Neuromuscular function is compromised in elite team handball players during periods of intensified competition or training (Ronglan *et al*., 2006), while mood disturbances become more prominent as training load is increased (Bresciani *et al*., 2010; Coutts *et al*., 2007; Halson *et al*., 2002). However, whether increased training load incurs similar responses in non-elite players is unclear. This information could prove valuable to coaches managing players during competition and contribute to the development of recovery strategies and training recommendations. The aim of this Study 3 (Chapter 5) was to investigate neuromuscular fatigue and well-being of British team handball players during a training camp and an international tournament.

Based on findings from Study 2 (Chapter 4) and Study 3 (Chapter 5), it was clear that appropriate interchange strategies needed to be investigated. There is some evidence to suggest that interchanged players set higher pacing strategies, completing greater overall distances and high-intensity effort bouts than 'whole-match' players (Black & Gabbett, 2014; Carling *et al*., 2010; Waldron *et al*., 2013). Therefore, in an attempt to limit match-induced fatigue and better maintain performance, it might be advantageous to investigate the effect of interchange strategies by manipulating player work and rest periods. To this end, Study 4 (Chapter 6) aimed to establish the effect of two different interchange strategies on performance and pacing strategy during a simulated team-sports protocol.

CHAPTER 2:

REVIEW OF LITERATURE

2.1 Anthropometric characteristics of team handball players

The contribution of physical characteristics to sports performance has been well established (Massuca *et al*., 2014; Malina *et al*., 2004). Indeed players in some sports are selected based on a clear physical prototype that deems them physically capable of reaching their full potential (De Garay *et al*., 1974). This has led researchers to investigate the physical characteristics associated with successful handball performance, which could potentially be utilised by coaches to select players. Awareness of the ideal characteristics could also direct coaches to aid the improvement of specific body composition requirements for athletes (Milanese *et al*., 2011).

A summary of the literature reporting the physical characteristics of team handball players is presented in Table 2.1 (males) and Table 2.2 (females). Taken from team average values, the tallest males are (~1.90 m) from players classified as elite or competing to national standard in Denmark, Slovenia, China and Croatia (Michalsik *et al*., 2011a; Šibila *et al et al*., 2010; Hasan *et al*., 2007a; Srhoj *et al*., 2002), while the tallest females (1.79 m) are from the Norwegian national team (Ronglan *et al*., 2006). The shortest male players are from the English national team (~1.74 m; Hasan *et al*., 2007a) and shortest female players are amateur players from Spain (~1.66 m; Granados *et al*., 2008). The heaviest males are elite Spanish players (~95 kg, Gorostiaga *et al*., 2006), while the Danish national team report the heaviest females (~75 kg, Urban *et al*., 2011). The lightest male body mass data were recorded from the French national team (~74.0 kg; Rannou *et al*., 2001), with Japanese players being the lightest of females (~60.6 kg; Hasan *et al*., 2007b).

For percentage body fat, values between 10.3% and 16.7% have been reported in male Saudi Arabian national team players (Hasan *et al*., 2007a) and 2nd and 3rd national division Norwegian players, respectively (van den Tillaar & Ettema, 2004). The lowest percentage of body fat for females has been recorded in Japanese players (~18.5%; Hasan *et al*., 2007b), while the highest values reported in female players are from sub-elite Italian championship players (~29.7%; Milanese *et al*., 2011).

As expected, elite youth male players are shorter than adults in stature, ranging from 1.60 m to 1.79 m (~14-15 y; Zapartidis *et al*., 2009a; Chelly *et al*., 2011) to ~1.80 m for U18 Flemish players (Matthys *et al*., 2011). Body mass values for youth male players range from 61.3 kg (elite players; Mohamed *et al*., 2009) to 79.2 kg (Greek first division players; Zapartidis *et al*., 2009a). Female youth players selected onto the Greek national programme were 1.66 m in stature, with body mass being 57.3 kg (age: 13-14 y; Zapartidis *et al*., 2009b). Given the range in playing standards of these studies, a greater number of studies are required to increase practitioner's knowledge of the anthropometric characteristics of elite youth players. Such information is imperative for selecting players with the required characteristics to compete at elite standard.

In an attempt to find a relationship between anthropometric characteristics and the relative performance of teams, researchers have analysed the characteristics of successful and unsuccessful teams (Milanese *et al*., 2011; Mohamed *et al*., 2009; Hasan *et al*., 2007a; Bayois *et al*., 2006; Gorostiaga *et al*., 2005; Rannou *et al*., 2001; Laska-Mierzejewska, 1978). An early study conducted by Larsa-Mierzejewka (1978) showed that top level female handball players were taller and heavier than players both one and two standards below them, in addition to a control group representing the general population. This was supported by Rannou *et al*. (2001) who confirmed that while international and national male handball players possessed similar morphological characteristics, international players were taller.

A direct comparison of players from the first and second division of the national handball Spanish league showed that elite male players had higher body mass (23%) and fat-free mass

(FFM; calculated as the difference between body mass and body fat) (11%) than second division players (Gorostiaga *et al*., 2005). However, there were no differences observed in stature (1.84 m *cf.* 1.88 m) and percentage body fat (11.6% *cf.* 14.9%) between amateur and elite players, respectively. The same research group also reported similar body mass and percentage body fat values between elite and amateur female players, but elite females were 6% taller with 10% greater FFM (Granados *et al*., 2007). Another study measured a variety of anthropometric characteristics in Italian elite and sub-elite females, which used Dual-energy X-ray absorptiometry (DXA) to show that elite players had significantly lower body fat percentage, higher bone mineral content, and greater lean mass in the upper limbs than sub-elite players (Milanese *et al*., 2011). However, no differences were observed in body mass (64.4 kg *cf.* 67 kg) or stature (1.66 m *cf.* 1.69 m) between sub-elite and elite players, respectively.

Using data from the top female Danish league, Michalsik and colleagues (2011b) reported no relationship between team ranking and stature, or body mass, nor did they observe any relationship between playing time and these two variables. That there is no difference between team ranking and anthropometric characteristics, particularly stature and body mass in this study, might be explained by an increased homogeneity between players once they reach an elite standard. Thus all players might possess the essential anthropometric requirements needed to compete at this standard, suggesting that other factors distinguish between more and less successful teams. Interestingly, this study also highlighted the much higher values of stature (~1.76 m) and body mass (~70 kg) in Danish female players compared to results taken from the top three female teams in the 1976 Olympic Games (1.72 m and 67.3 kg, Kholsa & McBroom, 1984). This suggests an increased need for players who are taller and heavier in today's modern game (Michalsik *et al*., 2011b).

Comparing data from male teams competing in the Asian National Championship, Hasan *et al*. (2007a) observed differences in various anthropometric characteristics. Successful teams were grouped as those placing first to third in the competition, whereas unsuccessful teams included fourth and fifth place. Results showed successful teams were taller (1.87 m *cf.* 1.82 ± m) with lower percentages of body fat (10.0 ± 1.1% *cf.* 11.9 ± 1.8%) and lower total values for the sum of five skinfolds (32.2 ± 4.3 mm *cf.* 38.6 ± 4.2 mm). However, there were no differences between teams in body mass and lean mass. Of particular interest, English and Kuwaiti players reported higher values for sum of five skinfolds and percentage body fat than players from the four other teams analysed. Asian players were acknowledged to be shorter and lighter than European players, highlighting the possible contribution of ethnic differences.

Youth handball players have shown differences between elite and non-elite players in body mass, arm length, arm span and both upper and lower limb circumferences, with elite players being ~8 cm taller than non-elite players (Mohamed *et al*., 2009). Selected youth players from another study were also found to be taller with a greater arm span than players who were not selected onto a national programme (Zapartidis *et al*., 2009a), thus demonstrating more successful players may already be prevalent in certain anthropometric characteristics before they reach adulthood.

Despite the difficulties associated with compiling information from studies measuring various parameters of anthropometry, these findings provide an overall consensus in favour of a tall stature and heavy body mass for successful performance in team handball (Gorostiaga *et al*., 2004; Rannou *et al*., 2001). A tall stature is advantageous when performing technical skills such as throwing, stealing, and handling the ball against an opponent (Matthys *et al*., 2011). However, the success of South Korea, comprising small and light female team players, has highlighted that it might be possible to compensate for low body mass and stature through selection of fast players possessing high technical and tactical skills (Michalsik *et al*., 2011b). High musculature or lean body mass (Milanese *et al*., 2011) are required to contest possession of the ball, whereas higher FFM (Granados *et al*., 2008; Gorostiaga *et al*., 2005) would imply greater economy for movement of body mass in movements such as jumping, running and sprinting (Hasan *et al*., 2007). However, the wide range of values reported in the literature for percentage body fat of elite players suggest that this might not be as important as other anthropometric factors. Furthermore, the distinct lack of studies assessing the anthropometric requirements in elite youth players highlights the need for further investigation. This information is valuable to youth team coaches for talent identification processes, and could be of importance when tracking youth players to adult competition.

Table 2.1: A summary of the anthropometric data for male team handball players. Values are mean ± SD unless stated

Study	Participants	Age (y)	Stature (m)	Body mass (kg)	Body fat %	Sum of skinfolds (mm)
Asci & Acikada (2007)	Experienced (*n*= 16)	22.6 ± 4.9	1.85 ± 0.06	86.1 ± 8.9	-	(∑7) 87.0 ± 2.5
Bucheit *et al*. (2009)	French national (*n*= 9) range	21.0 (18.1 – 21.9)	1.81 (1.78 – 1.84)	78.4 (72.6 – 84.2)	-	-
Chaouachi *et al*. (2009)	Tunisian national	24.3 ± 4.4	1.89 ± 0.06	88.6 ± 7.5	15.4 ± 3.7	-
	GK (*n*= 4)	26 ± 2.5	1.89 ± 0.02	91.5 ± 6.8	20.2 ± 1.4	
	Back (*n*= 9)	23 ± 1.2	1.93± 0.03	88.0 ± 8.0	12.4 ± 3.3	
	Pivot (*n*= 3)	24 ± 2.3	1.92 ± 0.07	98.2 ± 12.9	13.4 ± 2.6	
	Wing (*n*= 5)	23 ± 1.6	1.82 ± 0.05	84.1 ± 5.9	15.1± 2.8	
Gorostiaga *et al*. (2004)	Spanish national league second division (*n*= 15)	22.2 ± 4	1.84 ± 0.07	82.4 ± 10	11.6 ± 3	-
Gorostiaga *et al*. (2006)	Elite Spanish (*n*= 15)	31 ± 4	1.88 ± 0.07	T1:95.6 ± 14.3	14.9 ± 4.2	-
				T2:95.2 ± 13.4	13.9 ± 2.6	
				T3: 95.6 ± 12.1	13.6 ± 2.6	
				T4: 93.9 ± 16.9	14.0 ± 3.1	
Delamarche *et al*. (1987)	National division two players and finalists of French Championships (*n*= 7)	19.7 ± 1.11	1.80 ± 0.07	77.3 ± 7.5	-	-

Hasan *et al*. (2007a)	England (*n*= 8)	20 ± 2	1.74 ± 0.05	77.5 ± 11.5	13.4 ± 5.1	(∑5) 46.5 ± 18.5
	China (*n*= 10)	25 ± 3	1.90 ± 0.07	85.4 ± 10.0	9.6 ± 2.8	30.9 ± 7.8
	Japan (*n*= 16)	26 ± 2	1.85 ± 0.07	80.6 ± 3.9	9.2 ± 2.0	28.8 ± 5.3
	Korea (*n*= 7)	25 ± 2	1.85 ± 0.05	85.4 ± 8.7	11.2 ± 2.7	37 ± 9.1
	Kuwait (*n*= 17)	26 ± 3	1.82 ± 0.05	87.6 ± 10.3	12.9 ± 4.3	41.5 ± 15.4
	Saudi (*n*= 13)	25 ± 3	1.82 ±0.07	75.8 ± 8.1	10.3 ± 2.8	35.6 ± 9.4
Marques & Gonzalez-Badillo, (2006)	Experienced (*n*= 16)	23.1 ± 4.7	1.84 ± 0.13	84.8 ± 13.1	-	-
Michalsik *et al*. (2011a)	Danish Premier League (*n*= 191)	26 ± 4.4	1.90 ± 0.06	92.6 ± 8.5	-	-
	GK (*n*= 26)	28.5 ± 5.6	1.91 ± 0.04	94.1 ± 7.9		
	Back (*n*= 80)	25.8 ± 3.6	1.92 ± 0.05	94.7 ± 7.1		
	Pivot: (*n*= 33)	26.2 ± 5	1.95 ± 0.04	99.4 ± 6.2		
	Wing (*n*= 52)	24.9 ± 3.9	1.85 ± 0.06	84.5 ± 5.8		
Póvoas *et al*. (2014)	Portuguese professional league (*n*= 40)					
	GK (*n*= 10)	26.2 ± 4.1	1.90 ± 0.02	87.4 ± 8.7	10.0 ± 0.8	
	Back (*n*= 10)	25.7 ± 4.1	1.91 ± 0.06	89.8 ± 7.4	8.9 ± 1.5	
	Pivot (*n*= 10)	24.4 ± 3.9	1.92 ± 0.03	98.6 ± 4.9	10.0 ± 2.4	
	Wing (*n*= 10)	24.6 ± 2.8	1.77 ± 0.05	80.5 ± 6.1	10.5 ± 3.2	
Rannou *et al*. (2001)	French national (*n*=10)	22.7 ± 0.6	1.77 ± 0.01	74 ± 2.0	13.2 ± 0.9	-
	French international (*n*= 7)	23.9 ± 1.2	1.90 ± 0.01	79.4 ± 0.8	12.0 ± 0.4	
Šibila *et al*. (2010)	Slovenian national (*n*= 12)	18.9 ± 0.8	1.87 ± 0.06	89.5 ± 11	12.7	-

van den Tillaar & Ettema, 2004)	2nd and 3rd division Norwegian national competition (*n*= 25)	24.7 ± 2.3	1.85 ± 0.08	84.7 ± 10.0	16.7 ± 3.2	-
Srhoj *et al*. (2002)	Elite (Croatia and Bosnia-Herzegovina)	24.49	1.91 ± 0.07	91.3 ± 7.6		(∑7) 78.79
	GK (*n*= 7)		1.92	91.8		73.24
	Back (*n*= 23)		1.94	94.3		76.7
	Pivot (*n*= 6)		1.84	92.6		87.68
	Wing (*n*= 13)		1.87	85.1		77.54
Chelly *et al*. (2011)	Top national Tunisian youth division (*n*= 18)	15.1 ± 0.6	1.79 ± 0.05	70.1 ± 0.6	11 ± 1.2	-
Gorostiaga *et al*. (1999)	Regional youth Spanish (*n*= 9)	15.1 ± 0.7	1.73 ± 0.05	62.4 ± 7.1	11.3 ± 3.1	
Mohamed *et al*. (2009)	BHF players (*n*= 47)	15.0 ± 0.6	1.74 ± 0.08	61.3 ± 9.4	-	(∑5) 44.2 ± 15.8
	Elite (*n* = 18)	14.9 ± 0.6	1.79 ± 0.04	67.1 ± 6.4		45.6 ± 16.0
	Non-elite (*n*= 29)	15.0 ± 0.6	1.71 ± 0.08	57.5 ± 9.3		43.3 ± 16.1
Souhail *et al*. (2010)	Tunisian youth (*n*= 18)	14.3 ± 0.5	1.74 ± 0.1	64 ± 28.7	11.2 ± 3.9	
Zapartidis *et al*. (2009a)	Selected Greek youth national	14.13 ± 0.3	1.76 ± 0.07	68.82 ± 11.0	-	-
	GK (*n*= 4)	14.0 ± 0.3	1.73 ± 0.06	73.8 ± 16.3		
	Back (*n*= 19)	14.2 ± 0.3	1.79 ± 0.05	70.2 ± 9.2		
	Pivot (*n*= 2)	14.4 ± 0.1	1.79 ± 0.01	79.2 ± 13.3		
	Wing (*n*= 7)	14.1 ± 0.4	1.75 ± 0.05	62.0 ± 7.0		

Note: BHF = Belgium Handball Federation. ∑ = sum of skinfolds (mm). T1: beginning of the first preparatory period, T2: beginning of the first competitive period, T3: end of the first competitive period, T4: end of the second competitive period.

Table 2.2: A summary of the anthropometric data for female team handball players. Values are mean ± SD unless stated

Study	Participants	Age (y)	Stature (m)	Body mass (kg)	Body fat (%)	Sum skinfolds (mm)
Bayios *et al*. (2006)	Greek league (*n*= 222)	21.5 ± 4.6	1.66 ± 0.06	65.1 ± 9.1	25.9 ± 3.3	(∑5) 64.9 ± 16.5
Filaire & Lac (2000)	1st level French (*n*= 14)	24.1 ± 2.6	1.68 ± 0.05	61.0 ± 7.5	-	-
Garcin *et al*. (2003)	French (*n*= 11)	19 ± 0.8	1.68 ± 0.03	62.0 ± 5.2	-	-
Granados *et al*. (2007)	Elite Spanish (*n*= 16)	23 ± 4	1.75 ± 0.06	69.3 ± 8	19.2 ± 5.3	-
	Amateur (*n*= 15)	21 ± 3	1.66 ± 0.04	64.6 ± 5	23.3 ± 3	
Hasan *et al*. (2007b)	12th Asian games					
	China (*n*= 14)	21 ± 3	1.75 ± 0.04	64.8 ± 6.1	18.9 ± 3.0	(∑5) 45 ± 9.7
	Japan (*n*= 16)	24 ± 2	1.68 ± 0.07	60.6 ± 5.7	18.5 ± 4.0	42.2 ± 10.9
	Kazakhstan (*n*= 14)	23 ± 4	1.72 ± 0.09	68.7 ± 11.5	21.4 ± 5.5	56.2 ± 21.9
	Korea (*n*= 16)	21 ± 2	1.69 ± 0.05	64.7 ± 4.7	24.2 ± 2.2	62.5 ± 8.6
	GK (*n*= 11)	23 ± 2.1	1.76 ± 0.02	68.3 ± 6.3	23.3 ± 2.8	56 ± 11.9
	Back (*n*= 24)	22 ± 1.4	1.69 ± 0.03	62.2 ± 2.2	19.4 ± 2.4	49.7 ± 9.4
	Pivot (*n*= 13)	23 ± 4.0	1.72 ± 0.04	66.9 ± 4.5	20.6 ± 3.0	50.9 ± 9.8
	Wing (*n*= 12)	21 ± 2.0	1.7 ± 0.08	63.5 ± 2.9	21.8 ± 2.9	52.4 ± 7.8
Lian *et al*. (2005)	Elite Norwegian (*n*= 52)	22.8 ± 4.3	1.72 ± 0.06	68.8 ± 8.4	-	-
Manchado *et al*. (2007)	Elite German (*n*=16)	26.6 ± 3.8	1.76 ± 0.07	70.4 ± 6.8	-	-

Michalsik *et al*. (2011b)	Danish premier league female (*n*= 157)	25.4 ± 3.6	1.76 ± 0.06	69.8 ± 6.6	-	-
	GK (*n*= 26)	26.6 ± 4.0	1.80 ± 0.04	75.1 ± 6.1		
	Back (*n*= 63)	26.2 ± 3.3	1.77 ± 0.05	70.6 ± 5.3		
	Pivot (*n*= 27)	25.1 ± 3.8	1.78 ± 0.05	72.5 ± 4.9		
	Wing (*n*= 41)	23.7 ± 2.8	1.69 ± 0.05	63.5 ± 4.8		
Milanese *et al*. (2011)	Italian Championship					
	Elite (*n*= 26)	26.4 ± 5.8	1.69 ± 0.06	67.0 ± 7.9	23.3 ± 5.3	(∑8) 112.9 ± 26.1
	Sub-elite (*n*=17)	17.3 ± 2.3	1.66 ± 0.05	64.4 ± 10.5	28.6 ± 4.0	133.3 ± 27.8
	GK (*n*= 7)	24.0 ± 6.6	1.69 ± 0.07	74.7 ± 11.6	29.7 ± 4.5	149 ± 22.3
	Back (*n*= 14)	23.2 ± 7.0	1.71 ± 0.06	67.7 ± 7.5	25.1 ± 5.6	118.4 ± 24.6
	Pivot (*n*= 4)	23.7 ± 6.2	1.67± 0.04	66.6 ± 5.0	22.7 ± 6.3	114.2 ± 32.2
	Wing (*n*= 18)	21.8 ± 6.5	1.65 ± 0.04	61.0 ± 6.6	24.4 ± 5.0	113.5 ± 27.6
Ronglan *et al*. (2006)	Norwegian national				-	-
	Training camp (*n*= 7)	23.7 ± 2.1	1.79 ± 0.04	72.0 ± 6.3		
	International tournament (*n*= 8)	23.1 ± 2.0	1.76 ± 0.05	71.2 ± 1.8		
van den Tillar & Ettema (2004)	2nd and 3rd division Norwegian national competition (*n*=20)	22.2 ±2.6	1.71 ± 0.06	69.0 ± 8.7	28.4 ± 3.6	-

Vila *et al*. (2012)	Spanish top professional league (*n*= 133)	25.7 ± 4.8	1.71 ± 0.07	67.6 ± 8.1		(∑4) 77.6 ± 18.5 (∑6) 95.5 ± 23.5
	GK (*n*= 19)	26.5 ± 5.9	1.75 ± 0.06	69.3 ± 7.7		(∑4) 85.2 ± 22.6 (∑6) 101.7 ± 26.1
	Back (*n*= 36)	25.4 ± 4.6	1.74 ± 0.06	71.1 ±7.8		(∑4) 75.2 ± 17.0 (∑6) 94.5 ± 23.3
	Pivot (*n*= 18)	25.7 ± 4.1	1.76 ± 0.09	74.7 ±6.7		(∑4) 81.5 ± 18.8 (∑6) 107.6 ± 25.3
	Wing (*n*= 41)	24.9 ± 4.9	1.65 ± 0.05	61.2 ± 4.3		(∑4) 73.7 ± 14.5 (∑6) 90.1±18.6
	Centre (*n*= 16)	27.9 ± 4.4	1.70 ± 0.05	65.7 ± 6.30		(∑4) 78.6 ± 25.2 (∑6) 91.1 ± 27.2
Urban *et al*. (2011)	EHF W19 Europeans (*n*= 207)					
	Denmark		1.77	75.4		
	Netherlands		1.73	68.3		
	Austria		-	-		
	Serbia		1.74	71.2		
	Sweden		-	-		
	Romania		1.77	72.2		
	Croatia		1.77	73.2		
	Spain		1.73	71.9		
	Russia		1.76	70.4		
	France		1.74	69.6		
	Germany		1.75	71.8		
	Norway		-	-		
	Poland		1.78	72.9		
	Hungary		1.77	72.2		
	Slovenia		1.73	70.4		
	Ukraine		1.74	66.8		

Zapartidis *et al*. (2009a)	Selected Greek youth national	13.8 ± 0.5	1.66 ± 0.07	57.3 ± 7.9	-	-
	GK (*n*= 4)	13.8 ± 0.4	1.67 ± 0.06	59.1 ± 4.3		
	Back (*n*= 14)	14.0 ± 0.5	1.70 ± 0.05	60.6 ± 6.7		
	Pivot (*n*= 3)	13.7 ± 0.5	1.68 ± 0.04	65.3 ± 6.1		
	Wing (*n*= 10)	13.6 ± 0.4	1.59 ± 0.04	49.8 ± 4.2		
Zapartidis *et al*. (2009b)	Greek youth top league (*n*= 181)	14.1 ± 1.1	1.63 ± 0.07	57.5 ± 7.9	-	-
	Backs (*n*= 88)	14.1 ± 1.1	1.68 ± 0.05	59.0 ± 7.1		
	Pivots (*n*= 25)	14.3 ± 1.1	1.65 ± 0.05	64.0 ± 7.0		
	Centre Back (*n*= 40)	14.1 ± 1.0	1.61 ± 0.06	55.5 ± 5.7		
	Wings (*n*= 42)	14.1 ± 1.2	1.59 ± 0.06	51.4 ± 6.1		

***Note*:** EHF W19 Europeans = European Handball Federation Women's under 19 European Championship. ∑ = sum of skinfolds (mm).

2.1.1 Positional differences in anthropometric data of team handball players

The differentiation in physical characteristics between positions within a handball team has been identified by previous research, suggesting the specific requirement of skills and attributes (Vila *et al*., 2012). For example, one such physical characteristic could be vital for successful performance in one position, whereas the requirements of another position may deem it insignificant. Many studies in team handball corroborate this view, whereby findings indicate positional differences in stature, body mass, BMI, and circumferences in males (Chaouachi *et al*., 2009; Sibla & Pori, 2009; Srhoj *et al*., 2002) and females (Vila *et al*., 2012; Milanese *et al*., 2011; Rogulj *et al*., 2005). In contrast, one study analysing players taking part in the Asian Games failed to find any significant differences between positions in stature, body mass, body fat or lean muscle mass (Hasan *et al*., 2007).

Wings have consistently been shown to be the lightest and shortest of players (Vila *et al*., 2012; Milanese *et al*., 2011; Chauachi *et al*., 2009; Zapartidis *et al*., 2009b). When direct comparisons are made to other positions, wings were found to be significantly shorter than backs (Milanese *et al*., 2011; Chauachi *et al*., 2009; Srjoj *et al*., 2002), whereas two studies found them to have significantly lower statures than all other positions (Vila *et al*., 2012; Zapartidis *et al*., 2009a). Likewise, the majority of studies have found wings to be significantly lighter than all other positions (Vila *et al*., 2012; Zapartidis *et al*., 2009a; Srhoj *et al*., 2002). The low body mass values for wings found in the majority of studies might be explained by their role, requiring enhanced speed and agility to constantly gain optimal position placement when play switches from attack to defence (Milanese *et al*., 2011). The limited amount of body contact also eradicates the need to have a large muscle mass and thus total body mass. As most shots are taken from the 6 m line, players in this position are not often required to overcome high blocks, reducing the need to be tall in stature (Srjoj *et al*., 2002).

When considering other anthropometric characteristics, wings have smaller hand lengths than backs (Vila *et al*., 2012; Zapartidis *et al*., 2009a; Srhoj *et al*., 2002) and goalkeepers (Vila *et al*., 2012), and lower circumferences of the upper arm, waist, and hip than goalkeepers (Milanese *et al*., 2011). Analysis of girths and breadths also revealed lower values in elite female wing players compared to backs and pivots (Vila *et al*., 2012), while in elite males wings scored lower in all measurements compared to backs but not pivots or goalkeepers (Srhoj *et al*., 2002). Similarly, wings had lower breadth measurements than backs, pivots and goalkeepers (Srhoj *et al*., 2002). Collectively, results suggest the reduced importance of large circumferences, girths and breaths for wing players, highlighting that positional demands (requiring reduced body contact and other abovementioned requirements) permit smaller skeletal frames and body size.

Wings have been shown to have significantly lower body fat, as measured by sum of eight skinfolds and DXA compared to goalkeepers (Milanese *et al*., 2011). These results might highlight the redundant nature of excess fat mass for wing players who need to sprint quickly from opposing sides of the court. However, three studies have found no difference in body fat between positions (Vila *et al*., 2012; Chaouachi *et al*., 2009; Hasan *et al*., 2007). Reasons for such differences might relate to inconsistencies between studies when calculating body fat, or might be a consequence of differences in training practices between teams.

It is clear that while wing position players are most different in physical characteristics to other positions, backs, pivots and goalkeepers are more homogenous, with fewer differences in physical characteristics (Milanese *et al*., 2011). In particular, players competing in the three latter positions are required to be tall in stature with high muscle mass to successfully execute blocking and contact actions (Vila *et al*., 2012; Chaouachi *et al*., 2009). One study disputed this view, reporting similarities in stature between wings and pivots, stating the reduced need to match the tall stature of backs due to the execution of short-range shots

(Srhoj *et al.*, 2002). However, it must be noted that match demands and positional requirements could have changed somewhat from when this study was conducted, meaning such characteristics are now more essential to performance. Likewise, the lack of any anthropometric differences reported by Hasan and colleagues (2007) might be indicative of the homogeneity of the population analysed (i.e. Asian games), though more research between nations is needed before conclusions can be established.

Despite the majority of research recognising the homogeneity of pivots, backs and goalkeepers in a variety of anthropometric characteristics, research has acknowledged some distinctions between these positions (Vila *et al.*, 2012; Milanese *et al.*, 2011; Chaouachi *et al.*, 2009; Zapartidis *et al.*, 2009b). A tendency for greater body fat has been observed in goalkeepers, with 62% higher values, determined by skinfold assessment compared to backcourt players (Chaouachi *et al.*, 2009). Greater BMI in goalkeepers than backs has also been observed in adult (Milanese *et al.*, 2011) and youth female players (Zapartidis *et al.*, 2009b). The higher body fat in goalkeepers is not surprising considering their positional demands, which require the execution of quick and explosive movements within a small playing area, consequently necessitating reduced overall energy demands than players in other positions (Srhoj *et al.*, 2002). Moreover, greater skeletal breadths found in goalkeepers are beneficial for covering a greater proportion of the goal (Vila *et al.*, 2012; Srhoj *et al.*, 2002). Some research also reports the greater body mass of pivots compared to backs (Vila *et al.*, 2009; Zapartidis *et al.*, 2009b). A heavier body mass might prove useful for pivot position players, whose role requires maintenance of stance on the 6 m line, working against an active defence (Schroj *et al.*, 2002).

2.2 Physical performance characteristics of team handball players

2.2.1 Aerobic capacity of team handball players

A well-developed aerobic capacity ($\dot{V}O_{2max}$) has been long considered a fundamental basis for elite team handball performance (Delamarche *et al*., 1987). Using average team values from the studies reviewed (see Table 2.3), the $\dot{V}O_{2max}$ of male players ranged between ~52.8 ± 5.5 and 59.0 ± 4.8 ml·kg^{-1}·min^{-1}. The lowest values were reported in Tunisian national team players (Chaouachi *et al*., 2009) using a 20 m shuttle run test (Multi-stage Fitness Test; Leger & Lambert, 1982), and highest from the Danish national team (Jensen *et al*., 1999) using a laboratory test (no further details provided). Female values were somewhat lower ranging from 49.6 ± 4.8 ml·kg^{-1}·min^{-1} in elite Danish premier league players using an incremental treadmill test (Michalsik *et al*., 2014b) to 53.8 ± 2.7 ml·kg^{-1}·min^{-1} in Norwegian national team players, although the test method was not identified (Jensen *et al*., 1997). However, with only two studies reporting values in female adult players, it is difficult to establish a detailed analysis of the values required for successful team handball performance.

Aerobic capacity of youth players had a similar upper range compared to adults in both males (58.6 ± 3.8 ml·kg^{-1}·min^{-1} for Danish national players, age ~19 y, Jensen *et al*., 1999) and females (48.49 ± 4.51 ml·kg^{-1}·min^{-1} for selected Greek national programme players, age ~13-14 y, Zapartidis *et al*., 2009a). Lowest values for youth males and females were reported for Greek players in the first division who were not selected for the national youth programme (males: 49.53 ± 4.4 ml·kg^{-1}·min^{-1}, age ~14 y; females: 46.53 ± 3.92 ml·kg^{-1}·min^{-1}, age ~13-14 y, Zapartidis *et al*., 2009a). However, the fact that data concerning youth players is taken from a very small number of studies from some nations that are not classified as 'elite' highlights that further research is needed to establish the aerobic capacity requirements for successful team handball performance.

A comparison between playing standards (Rannou *et al*., 2001) showed no differences in aerobic capacity ($\dot{V}O_{2max}$) between male handball players of international (58.7 ± 0.9 ml·kg^{-1}·min^{-1}) and national standard (57.7 ± 3.1 ml·kg^{-1}·min^{-1}). Moreover, Gorostiga *et al*. (2005) found no differences in mean heart rate or blood lactate at any running speed when elite and sub-elite players performed a four-stage submaximal discontinuous progressive running test. This suggests that both groups of players from each study had already developed the aerobic capacity required for successful performance, and any additional increase would be unlikely to be of further benefit. This suggests that other factors, such as physical performance, anthropometric characteristics, and technical/ tactical aspects are likely to distinguish between the highest standards of performance in elite team handball.

In contrast to traditional methods of assessing $\dot{V}O_{2max,}$ which use continuous treadmill tests to exhaustion, more recent studies acknowledge the need to assess the ability of players to maintain repeated high-intensity intermittent running (Massuca *et al*., 2014; Michalsik *et al*., 2014a). As such, distance covered during the Yo-Yo Intermittent recovery tests (Yo-Yo IR1, Yo-Yo IR2; Krustrup *et al*., 2003; Krustrup *et al*., 2006a) has been used as an alternative measure due to their greater applicability to intermittent team sports (Souhail *et al*., 2010; Bangsbo *et al*., 2008; Krustrup *et al*., 2003). The test is a measure of an individual's ability to repeatedly perform intense exercise and their potential to recover (Krustrup *et al*., 2003). Elite males from the top Danish league were reported to cover 895 ± 184 m in the Yo-Yo IR2 test (Michalsik *et al*., 2014a). Using the Yo-Yo IR1 (which has greater suitability for youth players), two studies on elite youth males reported very similar distances (1831 ± 373 m, Souhail *et al*., 2010; 1840 ± 270 m, Matthys *et al*., 2011), suggesting that this standard could be a pre-requisite for success in elite youth match play. However, it is acknowledged that the distances covered by players from these studies might be indicative of the training philosophies used, making it imperative for more studies to investigate differences between playing standard. Indeed, comparison of standards in youth players found that elite players covered greater distances (~400 m) in the Yo-Yo IR1 than sub-elite players taken from three age groups (U14, U16, U18 years, Matthys *et al.*, 2011).

Although there are a restricted number of studies assessing aerobic capacity in team handball players, care must be taken when interpreting these data due to the use of different procedures. This includes direct assessment of $\dot{V}O_{2max}$ using incremental treadmill (Michalsik *et al.*, 2014b; Rannou *et al.*, 2001) or cycling (Delamarche *et al.*, 1987) tests, compared to indirect procedures using the 20 m multi-stage fitness test (Buchheit *et al.*, 2009; Chaouachi *et al.*, 2009; Zapartidis *et al.*, 2009a, 2009b), and the Yo-Yo IR1 (Matthys *et al.*, 2011; Souhail *et al.*, 2010), Yo-YoIR2 (Michalsik *et al.*, 2014a) and the 30-15 Intermittent Fitness Test ($30\text{-}15_{IFT}$, Šibila *et al.*, 2010). Accordingly, it would seem logical to establish a standardised and practical method for assessing $\dot{V}O_{2max}$ in team handball players.

Table 2.3: Aerobic capacity ($\dot{V}O2_{max}$) of team handball players. Values are mean ± SD unless stated

Sex	Study	Participants	Age (y)	$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	Method for determination of $\dot{V}O_{2max}$
Male	Bucheit *et al*. (2009)	French national (*n*= 9)	21.0	57.3	Graded maximal exercise test
		Range	(18.1 – 21.9)	(52.6 - 62.0)	
Male	Chaouachi *et al*. (2009)	Tunisian Senior National (*n*= 21)	24.3 ± 4.4	52.8 ± 5.5	20 m shuttle run test
		GK (*n*= 4)	26 ± 2.5	53.2 ± 5.4	
		Back (*n*= 9)	23 ± 1.2	53.4 ± 3.2	
		Pivot (*n*= 3)	24 ± 2.3	51.6 ± 8.3	
		Wing (*n*= 5)	23 ± 1.6	52.4 ± 5.6	
Male	Delamarche *et al*. (1987)	French national 2nd division (*n*= 7)	19.7 ± 1.1	58.3 ± 5.3	Incremental cycle ergometer test
Male	Jensen *et al*. (1999)	Danish national (*n*= 47)			Unknown (laboratory)
		Danish national (adult)	24.4 ± 3.5	59.0 ± 4.8	
		Danish youth national 1	19.7 ± 0.8	58.6 ± 3.8	
		Danish youth national 2	17.9 ± 0.7	57.5 ± 4.7	
Male	Rannou *et al*. (2001)	French national (*n*=10)	22.7 ± 0.6	57.7 ± 3.1	Incremental treadmill exercise test
		French international (*n*=7)	23.9 ± 1.2	58.7 ± 0.9	
Male	Šibila *et al*. (2010)	Slovenian national youth (*n*=12)	18.9 ± 0.8	50.9 ± 2.66	30-15_{IFT} test
Male	Zapartidis *et al*. (2009a)	Greek youth top league (*n*= 88)	14.1 ± 0.4	50.4 ± 4.6	20 m shuttle-run test (20-MST)
		Selected (*n*= 32)	14.1 ± 0.3	51.9 ± 4.6	
		Non-selected (*n*= 56)	14.0 ± 0.4	49.5 ± 4.4	

Female	Jensen *et al*. (1997)	Norwegian national (*n*= 8)	20.4 ± 2.3	T1: 51.3 ± 2.3 T2: 51.4 ± 1.9 T3:53.8 ± 2.7 T4: 53.5 ± 2.9	Not specified
Female	Michalsik *et al*. (2013b)	Elite Danish Premier league (*n*= 24) Back (*n*= 7) Pivot *(n*= 7) Wing (*n*= 10)	25.9 ± 3.8	49.6 ± 4.8 48.8 ± 4.5 49.3 ± 5.8 50.5 ± 5.0	Incremental treadmill test (breath-by-breath)
Female	Zapartidis *et al*. (2009a)	Greek youth top league Females(*n*= 73) Selected (*n*= 31) Non-selected (*n*= 42)	 13.7 ± 0.5 13.8 ± 0.5 13.6 ± 0.6	 47.3 ± 4.3 48.5 ± 4.5 46.5 ± 3.9	20 m shuttle-run test (20-MST)
Female	Zapartidis *et al*. (2009b)	Greek top league youth (*n*= 181) GK (*n*= 26) Back (*n*= 48) Pivot (*n*= 25) Wing (*n*= 42) Centre back (*n*= 40)	14.12 ± 1.09 14.08 ± 1.18 14.09 ± 1.06 14.28 ± 1.14 14.08 ± 1.2 14.1 ± 0.97	45.47 ± 5.92 42.86 ± 3.77 44.78 ± 8.69 43.61 ± 3.58 48.18 ± 4.24 46.27 ± 4.04	20 m shuttle run test (20-MST)

***Note*:** 30-15IFT = 30 s work and 15 s rest Intermittent Fitness Test (Buchheit *et al*., 2008). T1: Beginning of the preparation for a new season, T2: Middle of the preparation period, T3: Beginning of the season for the national league, T4: Before the most important tournament for the national team.

2.2.2 Speed and agility characteristics of team handball players

The ability to sprint and change direction at high velocities is an important determinant of performance in game activities (Buchheit *et al*., 2010; Ben Abdelkrim *et al*., 2007). Team handball continuously alternates between phases of attack and defence, requiring players to perform maximal sprints between 5 - 30 m to gain successful scoring opportunities and to regain defensive positions and prevent fast-breaks (Zapartidis *et al*., 2009a). A summary of studies reporting sprinting performance is presented in Table 2.4.

Differences in speed between elite and amateur players have been observed in females, with elite players performing ~2-3% faster over 5 m (1.10 ± 0.05 s *c.f* 1.14 ± 0.03 s) and 15 m (2.64 ± 0.09 s *c.f.* 2.71 ± 0.08 s; Granados *et al*., 2007). In comparison, Gorostiaga *et al*. (2005) found 5 m and 15 m sprint performance to be similar in elite (5 m: 1.03 ± 0.05 s; 15 m: 2.46 ± 0.09 s) and amateur males (5 m: 1.04 ± 0.03 s; 15 m: 2.41 ± 0.07 s). In youth male players, Zapartidis *et al*. (2009a) reported significant differences in 30 m sprint time between youth (age 13-14 y) male players who were selected (4.73 ± 0.27 s) and not selected (4.86 ± 0.26 s) onto the national programme. However, no differences were observed in female players (selected: 5.13 ± 0.22 s; non-selected: 5.23 ± 0.25 s).

Table 2.4: Sprint performance of team handball players. Values are mean ± SD unless stated

Sex	Reference	Participants	Age (y)	5 m (s)	10 m (s)	15 (s)	20 m (s)	30 m (s)
Male	Chouachi *et al*. (2009)	Tunisian national	24.3 ± 3.4	1.17 ± 0.05	1.92 ± 0.07			4.40 ± 0.14
Male	Jensen *et al*. (1999)	Danish national	24.4 ± 3.5	0.89 ± 0.08				4.11 ± 0.17
Male	Gorostiaga *et al*. (2005)	Elite Spanish	31.0 ± 3.0	1.03 ± 0.05		2.46 ± 0.09		
Male	Marques & Gonzalez-Badillo (2006)	Elite Spanish	~23			2.49 ± 0.13		4.33 ± 0.2
Male	Buchheit *et al*. (2010)	Well-trained youth Post Intervention (2 separate programmes)	16.0 ± 0.9		1.83 ± 0.0 – 1.94 ± 0.11			
Male	Jensen *et al*. (1999)	Danish youth national	19.7 ± 0.8 17.9 ± 0.7	0.86 ± 0.05 0.89 ± 0.05				4.08 ± 0.14 4.13 ± 0.16
Male	Zapartidis *et al*. (2009)	Greek youth national	14.13 ± 0.3					4.73 ± 0.28
Male	Matthys *et al*. (2012)	Belgian youth national	12.8 ± 0.7 13.9 ± 0.8 14.9 ± 0.8	1.2 ± 0.09 1.15 ± 0.06 1.12 ± 0.04	2.06 ± 0.13 1.94 ± 0.11 1.91 ± 0.09		3.57 ± 0.22 3.36 ± 0.22 3.29 ± 0.16	5.02 ± 0.30 4.75 ± 0.30 4.61 ± 0.23
Male	Ingebrigtsen *et al*. (2013)	Norwegian youth elite	U18 U16	-	1.93 ± 0.09 1.92 ± 0.01		-	4.51 ± 0.2 4.49 ± 0.22

Female	Granados *et al*. (2007)	Elite Spanish	23.1 ± 4.0	1.10 ± 0.05		2.46 ± 0.09		
Female	Ronglan *et al*. (2006)	Norwegian national	23.1 ± 2.0				3.10 ± 3.08	
Female	Ingebrigtsen *et al*. (2013)	Norwegian elite youth	U18 U16	-	2.04 ± 0.1 2.11 ± 0.1		-	4.87 ± 0.22 5.03 ± 0.22
Female	Zapartidis *et al*. (2009)	Selected youth Greek national	13.8 ± 0.47					5.13 ± 0.22

Sprint performance remains unchanged over the course of a season in both males (Gorostiaga *et al*., 2006) and female team handball players (Granados *et al*., 2008). These findings were attributed to progressive increases in training volume with a large contribution from endurance-type training throughout the season, as well as short time periods being dedicated to sprint training. Interestingly, positive correlations in both studies were observed between sprint performance and squat exercise (load 60% of body mass (BM) in females; 125% BM in males), suggesting the potential positive transfer of leg strength into improved sprinting performance (Granados *et al*., 2008; Gorostiaga *et al*., 2006). These findings support work by Marques and Gonzalez-Badillo (2006), who showed improved 15 m and 30 m sprinting performance in elite male handball players at six weeks (15 m: 1.57%; 30 m: 2.24%) and twelve weeks (15 m: 2.35%; 30 m: 3.13%) of a training programme combining dynamic strength, sprint and vertical jump power training twice weekly. The significant increase in 4 Repetition Maximum (RM) parallel squat performance over the training period, in addition to its positive association with 30 m sprint performance (r= 0.54) again highlights the positive transfer of leg strength to dynamic sprint performance. Despite the positive transfer found in team handball studies, other researchers have reported equivocal findings after strength and power training (Ronnestad *et al*., 2008; Kotzamanidis *et al*., 2005; Fry *et al*., 1991). The inconsistency between studies might be attributed to differences in the amount of specific sprint training during interventions, overtraining, or an intervention period which was too short for significant adaptation to occur (Ronnestad *et al*., 2008). Also acknowledged is the lack of specificity of single joint tests that isolate muscles, which greatly differ from precise coordination required between various muscle groups during sprinting (Marques & Gonzalez-Badillo, 2006).

2.2.3 Strength and power characteristics of team handball players

Effective production of maximal strength and power of the upper and lower body increase success in essential match-actions such as hitting, blocking, pushing, holding and jumping (Granados *et al*., 2008; Gorostiaga *et al*., 2005). For this reason, studies have aimed to investigate the characteristics of elite players, and design interventions to enhance these parameters in hope that they will benefit team performance.

Maximal bench press (1RM) is reported to be 22 - 23% higher in elite compared to amateur team handball players, in both males and females (Granados *et al*., 2007; Gorostiaga *et al*., 2005). Similarly, elite players produce higher muscle power outputs (20-25%) at submaximal loads (45 – 70% 1RM) during bench press exercise, while half-squat values are 16% and 12% higher in elite males and females, respectively (Granados *et al*., 2007; Gorostiaga *et al*., 2005). Such large differences in strength and power between elite and sub-elite players suggest that these characteristics are essential for successful performance in team handball. A summary of the absolute values for bench press are presented in Table 2.5.

Table 2.5: Bench press values of elite and amateur team-handball players. Values are mean ± SD unless stated

Sex	Study	Participants	1RM bench press (kg)	Contraction-type	Details
Male	Asci & Acikada (2007)	Experienced	77.2 ± 12.8	Concentric	Inter-sport comparison
Male	Chelly *et al*. (2010)	Elite youth (age: 19.6 y)	88.5 ± 10.5	Eccentric- concentric	-
Male	Chaouachi *et al*. (2009)	Elite	82.5 ± 14.5	Isokinetic	-
Male	Gorostiaga *et al*. (2006)	Elite	Pre: 104.8 ± 15.5 Post: 106.8 ± 11.3	Concentric	45 week season
Male	Gorostiaga *et al*. (2005)	Elite Amateur	106.9 ± 11.6 82.5 ± 0.99	Concentric	Skill level comparison
Male	Marques *et al*. (2007)	Elite	68.9 ± 8.8	Concentric	-
Male	Marques & Gonzalez-Badillo (2006)	Elite	Pre: 58.5 ± 10.6 Post: 74.7 ± 12.0	Concentric	12 week training intervention
Male	Souhail *et al*. (2010)	Elite	Mod pre: 88 ± 13 Mod post: 101 ± 10 Heavy pre: 91 ± 10 Heavy post: 97 ± 12	Eccentric- concentric	10 week moderate and heavy training intervention

Female	Granados *et al*. (2007)	Elite Amateur	Elite: 47.9 ± 6.2 Amateur: 36.7 ± 4.6	Concentric	Skill level comparison
Female	Granados *et al*. (2008)	Elite	Pre: 45.8 ± 5.7 Post: 48.9 ± 6.5	Concentric	45 week season
Female	Hoff & Almasbakk (1995)	Elite	Pre: 41.6 ± 2.24 Post: 55.1± 2.21	Concentric	9 week maximal heavy progressive training intervention

In comparison, studies have failed to report differences in vertical jump performance between elite (46.8 ± 7 cm) and amateur (46.9 ± 7 cm) males (Gorostiaga *et al*., 2005), as well as between elite (34.9 ± 5 cm) and amateur (33.0 ± 3.0 cm) females (CMJ with swinging arms; Granados *et al*., 2007). Neither did CMJ height distinguish between top elite (38.7 ± 4.7 cm) and non-top elite (38.5 ± 8.2 cm) male players from the Portuguese leagues (Massuca *et al*., 2014). These results are surprising considering the important role of jumping in various aspects of the game, such as shooting and blocking. However, it could be that this specific parameter contributes a lesser extent to performance than other strength and power-related movements such as sprinting and throwing.

Relationships between parameters of strength and power and anthropometric characteristics have also been reported in the literature. van den Tillaar and Ettema (2004) observed that isometric strength of the upper extremity was positively associated with body mass (r= 0.52 - 0.59) and fat-free mass (r= 0.58 - 0.64) in male and female players (correlations performed separately for each group). In comparison, two studies reported a negative relationship between anthropometric characteristics and indices of strength and power (Granados *et al*., 2008; Gorostiaga *et al*., 2006). Gorostiaga *et al*. (2006) found a correlation between individual relative changes in percentage of body fat and individual relative changes in upper body power production during the concentric phase of a bench press (30% 1RM). Similar relationships were also observed in females between changes in body mass or percentage of body fat and maximal concentric strength of the upper extremity, in addition to concentric power production during squat (load: 60% body mass). These results indicate that players who decreased body fat or body mass evidenced greater decreases in power (Gorostiaga *et al*., 2006), or both strength and power (Granados *et al*., 2008) than those demonstrating smaller decreases or even small increases in body fat. Reasons for this association remain unclear and should be investigated further as they could be detrimental to team handball performance.

2.2.4 Throwing performance of team handball players

Throwing ability is one of the most fundamental skills required for success in team handball (Chelly *et al*., 2010; Gorostiaga *et al*., 2005). As the final outcome of the game is dependent on the team scoring the most goals, players must execute their shots with greatest accuracy and velocity in an attempt to successfully get the ball past the goalkeeper. Effective throwing performance is determined by the ability of a player to execute the correct technique, appropriately timing the movement of body segments, in addition to possessing and correctly executing strength and power of the upper and lower limbs (Chaouachi *et al*., 2009; Gorostiaga *et al*., 2005). Table 2.6 shows a summary of studies investigating throwing velocity and in team handball.

Greater standing and three-step running handball throwing velocities have been reported for elite players when compared to their amateur counterparts (Wagner *et al*., 2012; Wagner *et al*., 2010; Granados *et al*., 2007; van den Tillaar & Ettema, 2006; Gorostiaga *et al*., 2005). Results for both standing and three-step running throw were 11% higher in elite females (Granados *et al*., 2007), while elite males scored 8% higher in standing throw and 9% higher in three-step running throw (Gorostiaga *et al*., 2005). Moreover, using stepwise discriminant analysis, B*ü*sch *et al*. (2013) identified that throwing velocity was the best predictor distinguishing between nominated and non-nominated female players for the German Youth National team over five years (classification probability >75.3%). This suggests that measures of throwing velocity could prove useful for talent identification purposes to distinguish amateur from elite players, but also when differentiating between elite and top-elite players.

Table 2.6: Summary of throwing velocity studies in team handball. Values are mean ± SD unless stated

Sex	Study	Participants	Standing velocity (km·h^{-1})	3-step velocity (km·h^{-1})		Result
Male	Bayios *et al*. (2001)	Greek national league		Cross-over step:	Jump throw:	Significant differences between groups in all types of throw
		Division 1 (*n*= 15)	84.64 ± 8.03	94.57 ± 11.56	81.86 ± 7.78	
		Division 2 (*n*= 15)	72.29 ± 4.03	83.59 ± 6.70	73.94 ± 5.87	
		Physical education students (*n*= 15)	60.66 ± 5.69	68.04 ± 7.13	55.94 ± 5.11	
Male	Chaouachi *et al*. (2009)	Tunisian national (*n*= 21)	85.57 ± 7.56 86.34 ± 4.78 88.76 ± 2.67 89.34 ± 5.45 88.00 ± 4.28	92.76 ± 12.56 94.45 ± 9.89 93.34 ± 6.78 99.67 ± 4.98 93.79 ± 8.57		-
Male	Chelly *et al*. (2010)	Tunisian top national league (*n*= 14)	-	82.80 ± 6.48		Significant relationship between throwing velocity and 1RM bench press, and force and power output of the upper and lower body
Male	García *et al*. (2011)	Elite (*n*= 18) Amateur (*n*= 24)	74.99 ± 5.15 56.74 ± 4.36	-		Significantly greater velocity and accuracy in elite
Male	Gorostiaga *et al*. (2006)	Elite Spanish (*n*= 15)	T1: 87.48 ± 8.28 T2: 85.68 ± 6.84 T3: 93.6 ± 7.92	93.24 ± 6.84 91.08 ± 7.92 99.36 ± 7.92		Significant increase from T1-T3 in both throws over 45 week season

Male	Gorostiaga *et al*. (2005)	Elite (*n*= 15) Amateur (*n*= 15)	85.68 ± 6.84 78.48 ± 5.76	91.08 ± 7.92 82.44 ± 5.04		Significantly greater velocity in elite over 45 week season
Male	Marques *et al*. (2007)	Elite (*n*= 14)	-	86.34 ± 6.12		Throwing velocity was related to maximal dynamic strength, peak power, and peak bar velocity
Male	Michalsik *et al*. (2014a)	Danish league (*n*= 26)	86.8 ± 6.4	92.8 ± 5.3	Jump throw: 84.2 ± 5.2	-
		GK (*n*= 3)	87.6 ± 8.8	90.4 ± 7.6	75.5 ± 4.9	
		Back (*n*= 7)	92.3 ± 7.1	98.6 ± 7.3	90.2 ± 6.3	
		Pivot (*n*= 7)	78.5 ± 4.9	84.3 ± 5.7	79.6 ± 5.9	
		Wing (*n*= 9)	88.6 ± 5.5	95.7 ± 5.8	86.0 ± 5.0	
Male	van den Tillaar & Etemma (2004)	Experienced Norwegian (*n*= 20)	83.52 ± 5.76	-		Relationship between throwing velocity and body size
Male	Vila *et al*. (2011)	Elite Spanish (*n*= 130)	7 m:74.09 ± 5.87 9m: 74.66 ± 5.58	81.07 ± 6.26	Jump throw: 79.13 ± 5.83	-
Male	Wagner *et al*. (2012)	Not experienced (*n*= 8) Experienced regional (*n*= 8) Elite Australian national and 2nd Austrian league (*n*= 8)		64.08 ± 7.56 81.72 ± 10.08 87.12 ± 10.08		Significant differences between playing standards for velocity and joint kinematics

Male	Wagner *et al*. (2010)	Elite (*n*= 12) Low level (*n*= 14)	-	Jump throw: 80.28 ± 5.4 64.8 ± 6.84	Significant differences between playing standards for velocity and kinematics
Female	Granados *et al*. (2007)	Elite (*n*= 16) Amateur (*n*= 15)	70.2 ± 3.96 62.64 ± 4.68	75.96 ± 4.68 67.68 ± 4.32	Significantly greater velocity in elite
Female	van den Tillaar & Etemma (2004)	Experienced Norwegian (*n*= 20)	69.12 ± 5.4	-	Relationship between throwing velocity and body size
Female	Zapartidis *et al*. (2009c)	Greek youth (~14 y) (*n*= 220)	56.77 ± 6.76	-	Significant relationship between throwing velocity and various anthropometric variables

Note: T1: beginning of the first preparatory period, T2: beginning of the first competitive period, T3: end of the first competitive period.

2.2.4.1 The relationship between throwing velocity and neuromuscular strength

Strength characteristics and their association to throwing velocity were investigated by Gorostiaga *et al*. (2005), who reported significant correlations between velocity at 30% of 1RM during a bench press and standing handball throw velocity in both amateur and elite male players (r= 0.67 - 0.71, $P < 0.05$). This suggests that players using a low bench press load relative to maximal values can execute higher velocities when throwing the ball from standing. Correlations in elite but not amateur players were observed between three-step running throw velocity and velocity at various percentages of 1RM bench press (r= 0.62), as well as with power at 60% and 100% of body mass during a half squat action (r= 0.61 - 0.62). The absence of correlations in amateur players might be due to a less efficient throwing action caused by poorer technique and lower strength and power. Thus, elite players are likely to have a better technique resulting from a more coordinated and efficient transfer of energy, which is aided by stronger and more powerful musculature. This agrees with Wagner *et al*. (2012), who observed higher three-step standing throwing velocities in elite players as well as differences in proximal-to-distal sequencing between skill levels. Thus, elite players were able to produce a more efficient transfer of momentum through the pelvis and trunk to the throwing arm (Wagner *et al*., 2012).

Various studies have found a positive relationship between throwing velocity and peak power during the bench press (Chelley *et al*., 2010; Marques & Gonzalez-Badillo, 2007; Granados *et al*., 2007; Gorostiaga *et al*., 2005). Marques and colleagues (2007) showed that three-step running throw in elite male players was significantly related to peak power at different loads during a bench press action using 36 kg and 46 kg, as well as with peak bar velocity at 26 kg and 36 kg (r= 0.56 - 0.63, $P < 0.05$). Absolute load lifted during 1RM bench press was also related to throwing velocity (r= 0.64). Similar results reported by Chelly *et al*. (2010) showed significant relationships between three-step throwing velocity and maximal bench press strength, as well as with peak power and force produced in a force-velocity test of the upper and lower body (r= 0.56 - 0.69, $P < 0.05$) in elite male players (age: ~19 y). These results differ from other studies finding no relationship between 1RM bench press and throwing velocity (Chaouachi *et al*., 2009; Gorostaiga *et al*., 2005). Although reasons for this are unclear, it is possible that players in the latter two studies trained this movement at low velocities, thus producing movement at a much slower velocity than is required during throwing (Chaouachi *et al*., 2009). However, as neither study provided specific information on the type of strength training performed, reasons for differences require further investigation.

In females, Granados *et al*. (2007) demonstrated a positive correlation between standing throwing velocity and 1RM bench press performance in elite and amateur female players, suggesting that higher maximal strength allows the ball to be thrown at a greater velocity for this type of throw. Similar associations using 1RM bench press (r= 0.88) have been shown in elite female players (Hoff & Almasbakk, 1995), in addition to the presence of a relationship between maximal specific isometric strength of the arm extensors and standing throwing velocity in Norwegian females from the second and third division (van den Tillaar & Ettema, 2004). These results highlight that female players should train to develop maximal strength of the upper body in order to improve standing throwing performance. However, correlations in amateur, but not elite females, were evident between three-step running throw and 1RM bench press, in addition to power at 80% of body mass related to fat free mass during half squat (r= 0.67, Granados *et al*., 2007). This finding could not be explained by the authors, who argue stronger muscles enable a more efficient transfer of energy needed for throwing. Further research is warranted to clarify the most important contributors to three-step throwing performance in both female and male team handball players.

Throwing performance has also been related to physical characteristics. van den Tillaar and Etemma (2004) reported positive correlations between throwing velocity and stature (male *r*= 0.60, female *r*= 0.52), body mass (male *r*= 0.54, female *r*= 0.49), and fat-free mass (male *r*= 0.62, female *r*= 0.69) in experienced players. Sex differences were strongly reduced when throwing velocity was adjusted for fat free mass, highlighting that greater lean body mass was the reason for greater throwing velocities in male players. Zapartidis *et al*. (2009c) also found significant correlations between throwing velocity and stature (*r*= 0.34), body mass (*r*= 0.23), hand length (*r*= 0.28), hand spread (*r*= 0.37, *n*= 120) and arm span (*r*= 0.34) in a large sample of youth female players (*n*= 220). In contrast, Chaouachi *et al*. (2009) found no relationship between throwing velocity and stature, body mass or percentage body fat in Tunisian national male players. Reasons for the disparity between findings are unclear but might be partly explained by lower standard deviations for stature and body mass in the latter study (5.5 cm and 7.5 kg) compared to the former studies (6.2 – 8.2 cm and 8.6 – 10 kg). Thus, less variance in the player sample by Chaouachi and colleagues (2009) might have reduced the r value.

2.3 Movement and physiological demands of team handball players during matches

Assessing the internal and external demands imposed on team-sport players has become commonplace (Michalsik *et al*., 2013a; P*ó*voas *et al*., 2012; Sirotic *et al*., 2009; Barbero-Alvarez *et al*., 2008; Coutts *et al*., 2010; Spencer *et al*., 2004), though information specifically on team handball is scarce. The array of time-motion analysis systems and the ease of collecting data from a non-invasive method enables researchers and coaches to acquire valuable data on the external load imposed on an individual player or whole team during training and competition (Chelly *et al*., 2011; Cunniffe *et al*., 2009; Coutts *et al*., 2003). External match demands have been represented in a variety of ways, including the frequency, mean duration and percentage of time spent in specific movement activities, as well as the total distance covered and total time (Duthie *et al*., 2005). Additional match data on average speeds, and key playing actions such as jumps, shots, changes in direction, body contact and activity changes have also been investigated (Michalsik *et al*., 2013a; Póvoas *et al*., 2012; Chelly *et al*., 2011; Ben-Abdelkrim *et al*., 2010; Spencer *et al*., 2004), further improving our understanding of the demands placed on team sport players. Methods of measuring internal load assess the responses of heart rate (Burke, 1998), perceived effort (Waldron *et al*., 2011), and sources of muscular energy, such as blood lactate concentration (Bangsbo, 1994), blood glucose (Jardine *et al*., 1988) and plasma free-fatty acids (Van Rensburg *et al*., 1986). Both of these approaches can be used to develop specific conditioning drills that imitate or overload the physiological demands that occur during match play (Pers *et al*., 2002; Deutsch *et al*., 1998), aid the estimation of energy requirements, and provide important information to prevent or reduce the occurrence of injury (O'Donoghue & Parker, 2002).

2.3.1 The movement demands of team handball

Total distance covered by elite male players is ~3,000 - 5,000 m (Michalsik *et al*., 2013a; Póvoas *et al*., 2012; Luig *et al*., 2008) when reported from league matches and tournaments using relatively large sample sizes and multiple matches. These values are similar to those reported by Pers *et al*. (2002), who showed that first division male Slovenian team handball players covered distances between 4,464 m and 5,088 m during a match. However, despite presenting data using a new tracking system, only a single match was used for analysis and no information on the total playing time was reported. The authors also failed to state the skill level of the opposition. *Š*ibila *et al*. (2004) reported a mean distance of 3,507 ± 317 m for outfield players, using data from six model matches, consisting of two 20 min halves using 84 Slovenian national players from youth, junior and senior squads. However, reporting combined results for three different age groups assumes that all players cover similar distance regardless of age, making it difficult to generalise these findings to real team handball match scenarios. Lower total distances have been reported in youth male players, with values of ~1,500 – 2,000 m (Chelly *et al*., 2011; Souhail *et al*., 2010). However, players from both of these studies were made up of teams matched for skill level, and were required to compete for two 25 min halves without substitutions, which is unlikely in competitive matches (Ronglan *et al*., 2006). Elite adult females cover similar distances to adult males during competitive matches ranging from ~2,800 m (Manchado & Platen, 2011) to ~4,000 m (Michalsik *et al*., 2014b). Both of these studies monitored competitive match play, making findings useful to better understand workloads imposed on female players at the elite standard. For a summary of the distance covered by team handball players please refer to Table 2.7.

The disparity in distance covered between male studies might primarily be due to the large variation in playing time. This relates to whether the movements of players were limited to while the ball was in play (effective match time), or whether the movement was also captured when match time was stopped for time outs, injuries, and two-minute suspensions (total match time). In the study by Luig *et al*. (2008), players were monitored while the ball was in play, totalling a mean playing time of 32:07 min. While Michalsik and colleagues (2013a) also assessed effective match time, their criteria to include players participating in at least 70% of total effective playing time meant that total playing time was higher (53:51 min). Greatest total playing time (~73 min) was reported by P*ó*voas and colleagues (2012) when monitoring players over a whole match (total match time). Additionally, the total distance covered by positions rather than the individual players was reported by Póvoas *et al*. (2012), substantially increasing the reported playing time. Although there are advantages to both types of analysis, it might be argued that neither give an accurate representation of total distance covered by players. The monitoring technique used by Michalsik *et al*. (2013a) excludes data from players participating in less than 70% of total effective playing time, thus only giving an average for players who compete for the longest match periods. The positional analysis conducted by Póvoas *et al*. (2012) can be useful for devising variations in training practices, but does not show an average of individual values, which would be useful to establish loading of players during competition. Other reasons for discrepancies might include the normal match-to-match variations in movement demands of team sports (Gregson *et al*., 2010; Bangsbo *et al*., 1991). Indeed, Michalsik *et al*. (2013a) highlights the potential problematic nature of most team handball studies that base findings on eleven matches or less, due to the large inter and intra-player variability between matches and position, as well as the differences between teams in terms of tactical and technical requirements.

In addition to the methodological issues, the lack of research detailing competitive matches in youth players is evident. The three known studies assessing youth male players all examined friendly matches (Chelly *et al*., 2011; Souhail *et al*., 2010; Šibila *et al*., 2004), which might not replicate the demands associated with competitive match play. More information on the movement demands of elite youth players in competition could help to identify the characteristics required for successful team handball match play. This could prove useful for emerging team handball nations such as England in order to gain a better understanding of the working demands and enable comparisons to the current English game. Through identifying key weaknesses and areas for progression, development of training practices could be employed to enhance the standard of play in England.

A small number of studies have assessed positional differences during matches (Michalsik *et al*., 2013a; Póvoas *et al*., 2014; Luig *et al*., 2008; Šibila *et al*., 2004), enabling a more comprehensive analysis of the specific requirements needed. Using this information might aid the development of more efficient training practices that target the demands of performance on a more individualised basis. Moreover, position specific analysis might be useful for identifying whether talented players embody particular characteristics that are beneficial to a particular position when selecting players.

Wings and backcourt players consistently cover greatest total distances during matches, followed by pivots, and goalkeepers. In the most comprehensive study of matches (*n*= 72), Michalsik and colleagues (2013a) reported that distances for backs (3,765 ± 532 m) and wings (3,641 ± 501 m), were higher than for pivots (3,295 ± 495 m). Póvoas *et al*. (2014) showed that backcourt players covered 15% greater distance than wings, and 21% more than pivots. In the only study to monitor individual players without restrictions (i.e. without inclusion constraints on playing time), Luig *et al*. (2008) showed that wings covered greatest distances (3,710 ± 210 m), which was significantly more than backs (2,840 ± 151 m) and pivots (2,787 ± 239 m). Wings were also involved in the most playing time (~37 min) compared to backcourt players (~29 min) and pivots (~29 min), which might be a contributing factor to explain this finding. As expected, goalkeepers covered the shortest distances (2,058 m) and played for ~37 min. Results from practice matches (2 x 25 min halves) showed total distance covered was greatest in wings (3,855 m), followed by backcourt (3,432 m), pivots (3,234 m), and goalkeepers (1,753 m) (Sibila *et al*., 2004). In contrast, elite female pivot (4,067 ± 485 m) and wing (4,086 ± 523 m) positions covered greater distances than backcourt players (3,867 ± 386 m) in analysis of the top Danish league, which might indicate differences in the role of the female pivot in comparison to male game.

Table 2.7: Total distance covered by team handball players during matches in team sport players. Values are mean ± SD unless stated

Sex	Study	Participants	Total distance covered (m)
Male	Luig *et al*. (2008)	2007 Men's World Cup (*n* = 170)	
		Goalkeeper (*n*= 20)	2,058 ± 90
		Back (*n*= 85)	2,840 ± 151
		Pivot (*n*= 25)	2,787 ± 239
		Wing (*n*= 40)	3,710 ± 210
Male	Michalsik *et al*. (2013a)	Danish top league (*n*=82)	3,627 ± 568
		Back (*n*= 41)	3,765 ± 532
		Pivot (*n*= 18)	3,295 ± 495
		Wing (*n*= 23)	3,641 ± 501
Male	Pers *et al*. (2002)	Slovenian 1st division (*n*= 6)	4,800
Male	Póvoas *et al*. (2012)	Top Portuguese professional league (*n*= 30)	4,370 ± 702
Male	Póvoas *et al*. (2014)	Top Portuguese professional league (*n*= 30)	
		Back (*n*= 10)	4,964
		Pivot (*n*= 10)	3,910
		Wing (*n*= 10)	4,234
Male	Šibila *et al*. (2004)	Slovenian national (youth, junior and senior, *n*= 84)	
		Goalkeeper (*n*= 12)	1,753
Male		Back (*n*= 36)	3,432
		Pivot (*n*= 12)	3,234
		Wing (*n*= 24)	3,855
Male	Chelly *et al*. (2011)	Top national division youth Tunisian (*n*=18)	1,777 ± 264
Male	Souhail *et al*. (2010)	Tunisian youth (*n*= 18)	1,921 ± 170
Female	Manchado & Platen (2011)	Norwegian national and German 1st league	2,882 ± 1,506 GK: 1,337 ± 293

Female	Michalsik *et al*. (2014b)		
		Danish top league (*n*= 83)	4,002 ± 551
		Back (*n*= 30)	3,867 ± 386
		Pivot (*n*= 18)	4,067 ± 485
		Wing (*n*= 35)	4,067 ± 485

Separating movement data into categories such as standing, walking, jogging, running sprinting, and sideways/ backwards movement, can greatly contribute to our understanding of match demands, player loading, and intensity requirements (Doǧramaci *et al*., 2010). The presentation of movement as the percentage of total distance covered, or percentage of total time spent within each category provides a framework for which training practices can be based in order to better replicate the demands of competition and prevent the onset of fatigue (Barbero-Alverez & Castagna, 2007; Duthie *et al*., 2003).

Team handball investigations in males have consistently shown that largest percentages of total distance covered per match are spent in low-intensity activities, defined as standing and walking (29% - 45.9%; Michalsik *et al*., 2013a; P*ó*voas *et al*., 2012; Chelly *et al*., 2011; Luig *et al*., 2008; Pers *et al*., 2002). High-intensity activities comprise smaller percentages of total distance covered in comparison (7.9 - 32%; Michalsik *et al*., 2013a; P*ó*voas *et al*., 2012; Chelly *et al*., 2011; Luig *et al*., 2008; Pers *et al*., 2002). This is typical of other intermittent team sports that are generally dominated by low-intensity movements, interspersed with periods of movements performed at high-intensity (Austin *et al*., 2011; Scanlan *et al*., 2011). However, obvious difficulties exist when comparing data on movement demands between studies because of the different criteria used to identify high- and low-intensity movement, variation in category definitions and classification speeds, as well as inclusion of additional movement categories, such as high-intensity sideways movement (e.g. P*ó*voas *et al*., 2012). In addition, specific inclusion criteria, where only players competing in a set percentage of total match time (Michalsik *et al*., 2013a), and differences between monitoring periods (effective vs. total match time) further confound these observations. This notwithstanding, a detailed analysis of the respective movements of team handball is presented in Table 2.8.

Table 2.8: Distance covered and percentage total time spent in each activity for team handball players. Values are mean ± SD unless stated

Sex	Study	Participants	Walk	Jog	Run	Fast run	Sprint	Sideways movement	Backwards run
Male	Chelly *et al.* (2011)	Top national division youth Tunisian (*n*= 18)	29%	59%	-	(HI run) 170 ± 24 8%	86 ± 12 4%	-	-
Male	Luig *et al.* (2008)	2007 Men's World Cup players	34.4 ± 4.9%	44.7 ± 5.1%	-	17.9 ± 3.5%	3.0 ± 2.2%	-	-
Male	Michalsik *et al.* (2013a)	Danish League (*n*= 82)	1,424 ± 265 39.2%	618 ± 155 17%	510 ± 121 14.1%	207 ± 91 5.7%	78 ± 91 2.2%	666 ± 242 18.4%	124 ± 76 3.4%
Male	Pers *et al.* (2002)	Slovene 1st division (*n*= 6)	(slow run) 31%	-	25%	7%	-	-	
Male	Póvoas *et al.* (2012)	Top Portuguese professional league (*n*= 30)	2,002 ± 427 45.9%	1,014 ± 335 23.2%	-	508 ± 282 11.5%	107 ± 87 2.4%	MI: 287 ± 173 6.5% HI: 183 ± 165 4.3%	268 ± 145 6.1%
Male	Póvoas *et al.* (2014)	Back (*n*= 10)	2,385 ± 306 40.9 ± 4.5%	1,225 ± 433 10.5 ± 4.3%	-	461 ± 292 1.9 ± 1.2%	97 ± 69 0.3 ± 0.2%	MI: 340 ± 133 6.0 ± 2.3% HI: 161 ± 130 0.9 ± 0.7%	295 ± 148 4.8 ± 2.3%
		Pivot (*n*= 10)	1,681 ± 396 29.9 ± 7.3%	1,049 ± 203 9.2 ± 2.0%	-	362 ± 183 1.5 ± 0.7%	57 ± 49 0.2 ± 0.2%	MI: 352 ± 219 6.4 ± 4.2% HI: 270 ± 222 1.6 ± 1.3%	139 ± 55 2.3 ± 0.9% 370 ± 110

		Wing (*n*= 10)	1,939 ± 237 34.1 ± 3.7&	768 ± 122 6.6 ± 1.0%	-	702 ± 262 3.0 ± 1.2%	168 ± 102 3.9 ± 2.4%	MI: 170 ± 90 3.1 ± 1.7% HI: 117 ± 88 3.1 ± 1.7%	6.2 ± 1.7%
Male	Šibila *et al.* (2004)	Slovenian national teams from youth, juniors and seniors (*n*= 84)	Standing and walking (<1.4 m·s^{-1})	(1.4-3.4 m·s^{-1})	(3.4-5.2 m·s^{-1})		(>5.2 m·s^{-1})		
		GK	86%	11%	2%		0.5%		
		Back	57%	25%	14%		3%		
		Pivot	63%	25%	10%		2%		
		Wing	58%	23%	14%		4%		
Male	Thorlund *et al*. (2008)	Simulation (*n*= 10)	265	2791	594	401	247	274	265
Male	Souhail *et al*. (2010)	Tunisian youth (*n*=18)	31 ± 7.3%	(LI run) 42 ± 3.6%		(HI run) 19 ± 9%	7.7 ± 3.1%		
Female	Manchado & Platen (2011)	Norwegian national team and German 1st league team (*n*=25)	961 ± 539 30.8 ± 5.9%	(slow run) 761 ± 420 29.1 ± 3.8%		752 ± 484 29.7 ± 3.9%	272 ± 224 10.5 ± 4.1%		
Female	Michalsik *et al*. (2014b)	Danish Premier female league (*n*= 83)	2,103 ± 334 52.6%	1,114 ± 219 27.8%	496 ± 252 12.4%	93 ± 67 2.3%	10 ± 11 0.2%	138 ± 99 3.5%	48 ± 32 1.2%

***Note*:** HI = high-intensity, MI = medium-intensity, LI = low-intensity

2.3.1.1 High-intensity activity during team handball matches

High-intensity activity is used as a valid measure of performance in soccer, whereby the frequency of sprints performed during a match discriminate between standard of competition (Bangsbo *et al*., 1991). In team handball, Michalsik *et al*. (2013a) showed that players in the top Danish League performed 53.2 ± 14.1 high-intensity runs (fast running [17 $km \cdot h^{-1}$]: 44 ± 18; sprinting [24 $km \cdot h^{-1}$]: 12 ± 11) with mean durations of 1.1 ± 1.3 s and 1.0 ± 4.5 s for fast running and sprinting, respectively. Almost identical frequencies (~52) were reported in the top Portuguese League, with slightly more sprints (22 ± 10 [25 $km \cdot h^{-1}$]) than observed by Michalsik and co-workers, as well as reduced frequency of fast running (30 ± 17.5 [$18.1 \cdot h^{-1}$]; Pόvoas *et al*., 2012). In addition, Pόvoas *et al*., (2012) reported slightly greater durations of activity than Michalsik *et al*. (2013a) for fast-running (3.1 ± 1.3 s) and sprinting (2.8 ± 1.1 s). In contrast, youth handball players exhibit somewhat lower frequencies of high-intensity running compared to adult players. For example, Chelly *et al*. (2011) reported 38 ± 6 high-intensity efforts (high-speed running and sprinting combined [>$18.1 \cdot h^{-1}$]) lasting for 2.0 ± 0.6 s, while Souhail *et al*. (2010) reported even lower frequencies of 19 ± 9, lasting between 1.7 s and 2.4 s (combining high-intensity running, moderate speed-running, high-speed running, sprinting, and sideways running [>15 $km \cdot h^{-1}$]). Collectively, these studies indicate handball players perform between 19 and 52 high-intensity actions per-match lasting between 1.0 s to 3.1 s. However, differing categorisations of high-intensity activity and methods of analysis confound the use of findings.

Positional analysis reveals that as well as covering the most distance, wing players also perform the greatest proportion of high-intensity running in both males (Pόvoas *et al*., 2014; Michalsik *et al*., 2013a; Luig *et al*., 2008; *Š*ibila *et al*., 2004) and females (Michalsik *et al*., 2014b). In the male Danish league, wings (10.9% of total distance covered) completed more high-intensity running than pivots (8.5%) and backs (6.2%) respectively (Michalsik *et al*., 2013a), which followed a similar pattern to that reported by P*ó*voas *et al*. (2014) in the male Portuguese league. The same positional differences were also observed in the female Danish league, although lower percentages of high-intensity running were apparent (1.3 – 1.6%, Michalsik *et al*., 2014b). Such results corroborate the finding that wing position players complete the highest number of sprints for the longest duration (P*ó*voas *et al*., 2014). Analysis of six experimental matches showed that wings spend the greatest proportion of total time in the sprinting category (>5.2 $m \cdot s^{-1}$) (4%) compared to backs (3%), pivots (2%) and goalkeepers (0.5%) (*Š*ibila *et al*., 2004). As expected, these findings indicate that less time is spent in low-intensity movement categories for wings and backcourt players. Backcourt players spend less time standing still and walking (~76%), compared to both wings and pivots (~80%; P*ó*voas *et al*., 2014). These re-affirm previous studies' findings, that are attributed the central positional requirements of backcourt position players, whom are involved in more constant movement than wings and pivots (Michalsik *et al*., 2013a; *Š*ibila *et al*., 2004).

2.3.1.2 Speed of movement

To the researcher's knowledge, only two studies in team handball have reported speed-related data during matches (Michalskik *et al*., 2013a; 2014b). Using knowledge of the time taken to cover known distances on the court and mean speed of each locomotive activity, mean movement speed during a match was estimated at 6.4 ± 1.0 $km \cdot h^{-1}$ for elite males (Michalsik *et al*., 2012) and 5.3 ± 0.4 $km \cdot h^{-1}$ for elite females (Michalsik *et al*., 2014b). Although movement speeds were found to be significantly higher in defence (6.8 ± 1.3 $km \cdot h^{1}$) than offence (6.1 ± 1.1 km·h^{-1}) in males, no differences were reported in females (defence 5.3 ± 0.47 km·h^{-1}, offence 5.3 ± 0.3 km·h^{-1}).

Relative to playing time, male team handball players cover ~70 m·min^{-1} (Michalsik *et al.*, 2013a) to ~92 m·min^{-1} (Luig *et al.*, 2009). Differences are likely to be a result of the shorter mean playing times (32:07 min) during the Men's World Championships (Luig *et al.*, 2009) compared to the Danish league (51:51 min; Michalsik *et al.*, 2013a). As players were substituted off more frequently during the tournament, it is possible that this contributed to better maintenance of higher running speeds throughout matches. Due to the potential positive implications of this strategy to limit fatigue and maintain performance, investigation into different interchange strategies could prove useful for team handball players during competition.

Analysis shows some discrepancy regarding the mean average speed in different positions. In one study on males, wing players had the highest average speed (5.8 km·h^{-1}), followed by backs (5.2 km·h^{-1}), pivots (4.82 km·h^{-1}) and goalkeepers (2.63 km·h^{-1}) (*Š*ibila *et al.*, 2004). However, Michalsik *et al.* (2013a) reported that mean average speeds were similar between all outfield positions (6.37 – 6.47 km·h^{-1}) in the male top Danish league. Further disparity occurs in female players showing that both wings (5.4 km·h^{-1}) and pivots (5.3 km·h^{-1}) had higher mean speeds than backcourt players (5.17 km·h^{-1}; Michalsik *et al.*, 2014b). When broken down into phases of play, male backs were found to work at a higher mean speed during offence (6.21 km·h^{-1}) compared to wings (6.0 km·h^{-1}) and pivots (5.8 km·h^{-1}, Michalsik *et al.*, 2013a). In contrast, back players had the slowest offensive average speed in analysis of the female league (Michalsik *et al.*, 2014b). In defence, both male and female pivots demonstrate a higher mean speed than backs but display similar speeds to wings (Michalsik *et al.*, 2014b; Michalsik *et al.*, 2013a). Differences in tactical playing style and match dynamics (e.g. conditions, opposition difficulty) might partly explain the inconsistency between positions. Moreover, these results indicate the potentially different requirements of positions in the male and female game, highlighting that training practices based on male analysis might not be appropriate for females.

2.3.1.3 Work to rest ratios during team handball matches

The relationship between high and low-intensity work is often expressed as a ratio, showing the mean time of recovery for every second of work. This provides an objective means of quantifying the physiological requirements of a match or training session (Duthie *et al*., 2003). Work to rest ratio data in team handball are sparse, but were reported by Chelly *et al*. (2011) to be as high as 1:2 in youth handball, where work was defined as high-intensity running or sprinting, and rest as standing, walking or jogging. Although not a specific work to rest ratio, data from P*ó*voas *et al*. (2012) , showed that players were able to recover from high-intensity activities for 90 s or more on 60% of all occurrences, in which they spent 52.4% of recovery periods in low-intensity movement, and ~50% standing still. However, research has acknowledged that work to rest ratios do not depict the most demanding periods or spurts of high-intensity work that are repetitive in nature with limited recovery time (King *et al*., 2009), highlighting that they should be accompanied by other forms of measurement such as video-analysis and heart rate data, when interpreting information.

2.3.1.4 Heart rate during team handball matches

The use of heart rate during training and competition is widely used as a means to gain information on physiological demands and the intensity of exercise (Achten & Jeukendrup, 2003). This is founded on the relationship between heart rate and steady state exercise, suggesting an increase in heart rate as work load increases (Hopkins, 1991). It is suggested that through the use of relative HR as a percentage of the individual maximal value, more informative data can be gained and used to inform future practice, than absolute values alone (Hopkins, 1991). Criticisms of heart rate monitoring have identified the logistical difficulties of collecting data (Duthie *et al*., 2003), the potential for psychological aspects such as anxiety to elevate heart rate prior to competition (Acevedo *et al*., 1999), and the slow response time of heart rate to exercise (Achten & Jeukendrup, 2003). Therefore, although heart rate in isolation does provide an index of physiological strain (Reilly & Thomas, 1979), it is useful to accompany findings with additional measures to develop a greater understanding of the physiological demands.

Very few team handball studies have reported heart rate data during matches (P*ó*voas *et al*., 2012; Chelly *et al*., 2011; Souhail *et al*., 2010; Delamarche *et al*., 1987; see Table 2.9). Average heart rates of 160 and 174 $b{\cdot}min^{-1}$ have been reported in adult males (French league players; Delamarche *et al*., 1987) and male youth players (Tunisian international; Souhail *et al*., 2010), respectively. Data representing HR as a percentage of maximal values have reported averages between 82% and 87% HR_{max} (effective match time), with lower values taken from the top male Portuguese league (P*ó*voas *et al*., 2012), and highest values taken from male youth Tunisian players (Souhail *et al*., 2010). From the three studies reporting peak HR data, elite males reached 185 ± 9.6 $b{\cdot}min^{-1}$ (P*ó*voas *et al*., 2012), while youth players experienced higher values of 198 ± 2 $b{\cdot}min^{-1}$ (99% HR_{max}; Chelly *et al*., 2011). Only three studies to the author's knowledge have assessed HR responses in females (Michalsik *et al*., 2014b; Manchado & Platen, 2011; Manchado & Platen, 2006), with average HR ranging from 162 ± 12 $b{\cdot}min^{-1}$ to 171 ± 7 $b{\cdot}min^{-1}$ during effective match time (Manchado & Platen, 2006; Michalsik *et al*., 2014b, respectively).

Using HR zones, Chelly *et al*. (2011) showed that male youth players competed for 10% of total match time in very vigorous activity (>85% HR_{max}), 64% in moderate (65-85% HR_{max}), and 28% in light activity (<65% HR_{max}) using zones recommended by Woolford and Angrove (1991). However, the large percentile range within each category does not provide specific information on the intensity of match play. As an alternative representation of data, the authors reported that players exceeded 170 $b \cdot min^{-1}$ for 72% of total playing time, which they classified as vigorous activity. However, using this method of describing match intensity may be problematic due to the individual differences in maximal heart rate, highlighting the need to establish more specific zones that are representative of individual values. It is possible that this study also overestimated values, as players were required to compete for 2 x 25 min periods, which is unusual in team handball matches, whereby coaches make use of substitutions (Luig *et al*., 2008). In elite male Portuguese players, 53% of effective match time was completed at intensities above 80% HR_{max}, with only 7% spent at intensities equal to or below 60% HR_{max}. On average, players competed at 82% HR_{max} (P*ó*voas *et al*., 2012). When considering total match time (including all suspensions, injury time and the half-time break), HR_{max} decreased to 72% (P*ó*voas *et al*., 2012). Similar results were reported in male youth handball (~82% HR_{max}), with players competing for 83% of time at intensities >85% HR_{max}, with HR rarely decreasing below 150 $b \cdot min^{-1}$ (Chelly *et al*., 2011). Moreover, heart rate was found to increase as the match progressed in an assessment of seven youth players but remained within 20 $b \cdot min^{-1}$ for each player during training matches (Delamarche *et al*., 1987). However, rule changes and game developments since 1987 mean it is likely that these findings do not accurately represent the increased intensity of the modern game. More recent findings show that values for elite females are similar to males, ranging from 78% HR_{max}, using results of two matches (Manchado & Platen, 2011) to 87% HR_{max} from seven national team matches (Manchado & Platen, 2006).

These data highlight that players are required to maintain vigorous to very vigorous activity for most of the match, and require a high aerobic capacity to uphold such high demands of competition (Gorostiaga *et al*., 2006; Manchado & Platen, 2006). This is likely to be a result of the high eccentric-related demands of the muscular systems (Póvoas *et al*., 2012), and emphasises that training practices should incorporate drills that enable players to prepare adequately to maintain high-intensity work throughout matches.

Positional analysis reveals higher mean heart rates in pivots (83 ± 9% HR_{max}) and backcourt players (84 ± 9% HR_{max}) compared to wings (79 ± 9 HR_{max}), thus suggesting that although wings cover larger distances in higher locomotive categories, these are often short-lived and are followed by less intense recovery periods (Póvoas *et al*., 2014). In contrast, pivot players constantly undergo physically demanding actions (e.g. on-on-one situations) that require them to work at a high percentage of HR_{max}. The same study also showed that wings were able to maintain HR intensity during the second half of matches, whereas intensity decreased in backcourt and pivot position players (Póvoas *et al*., 2014). This is likely to be a consequence of the reduced time spent in highly demanding playing actions against other players for wings compared to other positions, meaning that muscular fatigue is less pronounced in players of this position. It is also apparent that the contribution of pivot players is much greater during defence compared to attack (4.6% *cf.* 2.0%), which reaffirms their physical contribution when trying to prevent the opposition from scoring (Póvoas *et al*., 2014).

Table 2.9: Mean heart rate and percentage of heart rate maximum during team handball matches. Values are mean ± SD unless stated

Sex	Study	Participants	Mean HR ($b \cdot min^{-1}$)	% HR_{max} ($b \cdot min^{-1}$)
Male	Delamarche *et al*. (1987)	French national 2nd division (*n*= 7) range	160 – 180	-
Male	Michalsik *et al*. (2014a)	Danish top league (*n*= 41)	163 ±5	
Male	Póvoas *et al*. (2012)	Top Portuguese professional league (*n*= 30)		
		Effective match HR	157 ± 18	82 ± 9
		Total match HR	139 ± 32	72 ± 17
Male	Chelly *et al*. (2011)	Top national division youth Tunisian (*n*= 18)	172 ± 2	82 ± 3
Male	Souhail *et al*. (2010)	Tunisian youth (*n*= 18)	174 ± 3	87
Female	Michalsik *et al*. (2014b)	Danish top league (*n*= 45)		
		Active match play HR	171 ± 7	
		Effective match HR	163 ± 11	
		Total match HR	162 ± 8	
Female	Manchado & Platen (2011)	Norwegian national and German 1st league (*n* =25)	- -	78 ± 6 GK: 87 ± 5
Female	Manchado & Platen (2006)	German national (*n*= 12)	162 ± 12	87 ± 6

Note: GK = goalkeeper

2.3.1.4 Blood lactate concentration during team handball matches

Blood lactate concentrations have been used by researchers to indicate the contribution of energy metabolism from anaerobic glycolysis (Matthew & Delextrat, 2009; Ben-Abdelkrim *et al*., 2007). However, very few team handball studies have monitored responses during matches (Michalsik *et al*., 2014a; Chelley *et al*., 2011; Delamarche *et al*., 1987). In the most recent study, Michalsik and colleagues (2014a) reported values between 3.7 ± 1.6 mmol·l^{-1} and 4.8 ± 1.9 mmol·l^{-1} for end of first and second half of matches, respectively. Large individual variation in post-match values ranged from 2.8 – 10.8 mmol·l^{-1}. Somewhat higher values were reported in youth male players (9.7 ± 1.1 mmol·l^{-1} for first half and 8.3 ± 0.9 mmol·l^{-1} for second half), which might relate to the omission of substitutions. In the only study to assess blood lactate concentrations throughout a handball match, Delamarche *et al*. (1987) took samples every 5 min and reported that maximal values ranged from from 4 to 9 mmol·l^{-1} in a sample of seven players during a practice match. Three of the most active players were found to produce peak concentrations greater than 7.5 mmol·l^{-1}, and were able to compete for 20 - 30 min with concentrations greater than 4.0 mmol·l^{-1}, thus highlighting their ability to work for long durations at high intensities. Through use of an activity score detailing time-motion variables and technical actions, the authors reported a linear relationship between lactate production and player exertion. However, this study highlighted some of the problems associated with using blood lactate as a measure of physical exertion, showing inter-variability in lactate production between players despite recording the same activity score. Therefore, the use of lactate to adequately represent the relative work load between individuals may be limited, due to more efficient rates of lactate disappearance in some individuals compared to others. Other research has highlighted the questionable use of blood lactate as an accurate indicator of metabolism, pertaining that muscle and blood lactate did not correlate during a female football game (Krustrup *et al*., 2005) or during the Yo-Yo intermittent recovery test (Krustrup *et al*., 2003). Muscle lactate was also not associated with a decline in sprint performance during a match, thus suggesting that its use to determine energy metabolism and establish implications for fatigue are limited (Krustrup *et al*., 2006b). Furthermore, in an analysis of basketball performance, Ben-Abdelkrim *et al*. (2007) suggested that blood lactate values are only useful to indicate the demands of activity that occurred 5 min previous to the sample being taken, suggesting that it may be better to sample lactate at regular intervals in play when convenience allows. However gaining regular access to players during matches is logistically difficult. This, coupled with the potential for other factors to influence blood lactate concentration, such as prior glycogen status, hydration, prior exercise, and extraneous factors such as the ambient temperature (Borresen & Lambert, 2009; Meussen *et al*., 2006) suggests that its use should be complemented with other measures. However, if measurements can be taken at regular intervals, it does appear to provide useful information on the acute demands of exercise.

2.3.1.5 Activity changes during team handball matches

The frequency of change in movements provides essential information on how often players are required to continuously change speed via accelerations and decelerations, which place large loads on the physiological system (N*é*d*é*lec *et al*., 2012; Osgnach *et al*., 2010). P*ó*voas *et al*. (2012) reported that elite male players changed activity 825 times at 6 s intervals over a total playing time of 73 min. In Danish top league male players, Michalsik *et al*. (2013a) reported more frequent changes in activity (1,482), corresponding to a change every 0.46 seconds (although re-calculation of this data revealed an error in the manuscript and instead should state that a change in activity occurred every 2.18 s), or 28 changes$\cdot$min^{-1}, in players competing for ~54 min s. Full time players, competing for the total match time changed activity up to 2,000 times per match. Such large differences might be because of the use of different movement categories between studies. Although eight categories in total were used for both studies, Michalsik *et al*. (2013a) divided running into four categories (moderate jogging, running, high-intensity running, and sprinting) whereas P*ó*voas *et al*. (2012) used one less running-related category, and divided sideways movement into high and low-intensity. It is important to note that Póvoas *et al*. (2012) analysed footage from the whole match, including all time-outs, injuries and other occurrences, thus potentially reducing the rate of change in movement activity. It is also unclear whether this study excluded the half-time break in the analysis, as oppose to Michalsik *et al*. (2013a) who analysed data only when the ball was in play.

Souhail *et al*. (2010) reported 350 activity changes in youth handball matches, corresponding to an activity change every 4.1 s (however, re-calculation of this data revealed an error in the manuscript and this in fact should state that a change in activity occurred every 8.57 s). Despite a lower number of movement categories, more changes of activity (501) were recorded by Chelly *et al*. (2011), altering every ~5.9 s of play. The older players in the study by Chelly and colleagues (2011) (15.1 ± 0.6 y *cf.* 14.3 ± 0.5 y) might have contributed to the greater frequency of changes, possibly owing to maturation, improved playing style, or better physical conditioning. The shorter duration of matches (~25 min) for youth players will explain the much lower values reported compared to adult males, in addition to a difference in the movement categories used. Overall, the large number of changing actions during team handball match play, involving frequent accelerations and decelerations suggests that players are exposed to a vast physiological load, which is apparent even when speeds are low (Michalsik *et al*., 2013a; Osgnach *et al*., 2009).

2.3.1.6 Playing actions during team handball matches

Acyclic activities, such as tackles, shots, jumps, fakes, falls, blocks and side-cuttings are also inherent in team handball. These activities contribute considerably to the physical loading of the player (Michalsik *et al*., 2013a; Šibila *et al*., 2004). However, their relative impact on the overall working demands are not well understood (Singh *et al*., 2011, 2010; Johnston & Gabbett, 2011). Through gaining such data, technical match analysis can be applied and used to improve team performance and enhance knowledge of the overall physical demands (Pers *et al*., 2002).

Very few studies in team handball have reported extensively on the multitude of actions contributing to player loading. In the study by Pǿvoas *et al*. (2012), data showed that players, on average performed 13.8 ± 6.14 jumps, 6.7 ± 3.95 shots, 31.4 ± 12.4 stops, 30.6 ± 12.3 changes of direction, and 20.3 ± 15.7 one-on-one situations. This study showed that the most frequent movements analysed were stops and changes of direction, accounting for 60% of the 103 registered playing actions. When broken down into phases of offence and defence, players were involved in more physically demanding activity during defence, corresponding to a greater frequency of stops (17.9 ± 9.15 *cf.* 13.6 ± 6.42), changes of direction (17.5 ± 9.34 *cf.* 13.2 ± 6.2) and one-on-one situations (12.1 ± 8.82 *cf.* 8.2 ± 8.76). This suggests that players need to be proactive during defence, ensuring that they are physically competent to maintain the increased activity required for this phase of play.

In youth handball, a mean of 133 ± 15 specific technical activities were identified during a game; these activities occupied 22% of playing time (Chelly *et al*., 2011). Seven specific activities comparing the second half to the first showed 49.2 vs. 51.7 passes, 4.7 vs. 5.4 shots, 9.2 vs. 11.3 engagements, 10.5 vs. 8.8 dissuasions, 7.1 vs. 10.3 fixing actions, 5.7 vs. 5.6 dribbling actions, and 42.8 vs. 45.9 jumps, respectively. In another study, Souhail *et al*. (2010) reported 118 ± 51 passes, 134 ± 9.1 blocks, and 28 ± 4.3 interceptions in youth players for the entire match. Frequency of shots were much lower in this study when compared to elite adult team handball (18 ± 3.7 *cf.* 31.4 ± 12.4) possibly owing to enhanced quality of attacks in adult players compared to youth, thus resulting in more shooting opportunities. In contrast, jumping was much more frequent (35 ± 4.9 *cf.* 13.8 ± 6.14) in youth players, which might be a result of different operational definitions in this variable (i.e. whether a jump shot placed into the jump category, shot category, or both).

Michalsik *et al*. (2013a) reported that during organised attacks, pivot position players underwent more physical contact with opponents, which is a consequence of their positioning among defensive players on the 6 m line. Another study showed that although backcourt players underwent a greater frequency of jumps, throws and changes of direction than players in other positions, pivot position players performed more one-on-one situations (P*ó*voas *et al*., 2014). Collectively these results highlight the physical role of the pivot throughout the match, making strength and power training a more essential component of conditioning than other positions.

Overall, data highlight that players incur high stress to the aerobic and anaerobic pathways throughout a match, however distinct positional differences should be recognised and adapted into training practices (Michalsik *et al*., 2013a). Research shows that wings are required to perform short-bursts of high-intensity work while covering the greatest distances (Michalsik *et al*., 2013a; Luig *et al*., 2008; *Š*ibila *et al*., 2004), and relatively small amounts of body-contact (P*ó*voas *et al*., 2014). Such findings make it reasonable to suggest that training should focus more on speed-interval work and less on strength and power in order to maximise performance. Although pivots do not cover as much total distance as other outfield positions, their high amount of physical loading during one-on-one situations (P*ó*voas *et al*., 2014; Michalsik *et al*., 2013a) highlight that coaches should work on improving overall strength, and anaerobic capacities to run back quickly to defend the goal (Michalsik *et al*., 2013a). Competing in the central area of the court, the all-round nature of backcourt players having to perform two-fold more playing actions than wings (P*ó*voas *et al*., 2014), maintain intensities at a high percentage of HR_{max} (P*ó*voas *et al*., 2014) and cover large total distances (Michalsik *et al*., 2013a; Luig *et al*., 2008; *Š*ibila *et al*., 2004) suggest that they should be both strong, powerful, and have well-developed aerobic as well as anaerobic capacities.

2.3.2 Performance analysis of team handball performance

Key playing actions have also been reported as a mean of the team or individual positions. This analysis of performance is the study of player interactions through the use of indicators, defined as a selection of action variables used to measure player or team performance (Hughes & Bartlett, 2002). Key areas of focus for performance analysts include general match indicators, (e.g. shots taken, goals scored, and assists), technical indicators (e.g. efficiency [shots taken divided by goals scored], and unforced errors), and tactical indicators, (e.g. speed of attack, and the number of passes per phase). Examining these indicators provides greater understanding of the physiological, psychological, as well as technical and tactical demands of performance (Hughes & Bartlett, 2002). Moreover, coaches and practitioners can gain important information on team organisation and selection, kinematics, and intervention effectiveness (Barris & Button, 2008; Foretić *et al*., 2004).

Performance analysis studies in team handball have mainly provided descriptive information on indicators of performance (Curitianu *et al*., 2012; Ohnjec *et al*., 2008; Gruić *et al*., 2006), and completed comparative analysis between successful and unsuccessful teams (Foretić *et al*., 2010; Ohnjec *et al*., 2008; Gruić *et al*., 2006). The majority of these data have been taken from results gained at major competitions. Gruić *et al*. (2006) analysed 120 records of play in attack from the 2003 Men's World Championship in Portugal, showing that average shot and shot effectiveness during matches were 51 and 53.2% respectively. Most shots were taken from backcourt positions (21; 38.5%), followed by wings (8; 55.7%), 6 m line (9; 62.5%) and finally 6 shots were taken from fast breaks with an efficiency of 70.6%. Frequency of technical errors (15.86) was greater than the number of assists (12.04). Much greater shot efficiencies were reported by Curitianu *et al*. (2012) with values as high as 79 - 92.7% during the qualifying round of the Champions League, which might be partly explained by advances in the game after 2003. However, this study monitored players from one team, and only focused on six players in the wing and pivot positions, thus excluding the contribution from other team players and making findings difficult to generalise.

Only one study has analysed performance using these methods in female players (Ohnjec *et al*., 2008). From 60 matches (analysis of 120 teams) in the 2003 World Championship, shot frequency and shot efficiencies (~52 and 52.5% respectively) were similar to values reported from the men's equivalent competition (Gruić *et al.,* 2006). Backcourt players took the most shots (~23; 34.1%), followed by wings (~10; 50.1%), 6 m line (~6; 70.0%), with fast break shots averaging ~6, of which 76.9% were successful. When comparing this to males, females appear to be more efficient in scoring from 6 m (62.5% *cf.* 70.0%) and fast breaks (70.6% *cf.* 76.9%), whereas males are more efficient in the wing position (55.7% *cf.* 50.1%; Ohnjec *et al*., 2008; Gruić *et al*., 2006). Technical errors averaged 15.3, with a slightly greater number of assists in females (15.3) than males (12.0, Gruić *et al*., 2006). These findings show subtle differences between the male and female games, which might be because of differences in tactics or style of play that should be recognised when comparing players' performances, and informing training practices.

One method of determining the most important contributors to performance is to analyse the differences in key variables between successful and unsuccessful teams. Data from the 2003 Men's World Championship revealed that although successful and unsuccessful teams took the same number of shots during a match (~51), better teams were more efficient, scoring 62.3% of shots compared to 44.3% (Gruić *et al*., 2006). However, successful female 2003 World Championship teams were found to take more shots and were also more efficient in all positions (Ohnjec *et al*., 2008). Data from the male tournament in 2009 found a greater number of shots from positions close to the goal (6 m, wing, and fast break) translated into more goals and higher efficiencies (Foretić *et al*., 2010). In comparison, defeated teams were found to shoot more from 9 m (23.7 *cf.* 19.3) and scored less (8.0 *cf.* 10.0), suggesting that more successful teams are able to organise themselves to shoot from more effective positions (Foretić *et al*., 2010). These results highlight that lower quality teams have lower levels of technical and/ or tactical proficiency to create scoring opportunities, causing them to shoot before a systematic attack had been organised, or as a result of pressure from the passive play rule (Gruić *et al*., 2006). Other notable differences included higher scoring efficiencies from fast breaks, a greater number of assists, and a lower number of technical errors for successful compared to unsuccessful teams (Foretić *et al*., 2010; Ohnjec *et al*., 2008).

These studies offer a valuable insight into the technical and tactical demands of team handball matches. However, researchers have stressed that current analyses are insufficient to be useful in applied settings to inform coaching practice (Meletakos *et al*., 2011). Therefore, more studies that include a greater number of potential match-influencing variables should be researched, giving a greater overall picture of all the important elements of player quality (Foretić *et al*., 2010). Such analysis could be used for player selection purposes, and to inform training practices to enhance overall team performance. Furthermore, there are no detailed analyses of players at the youth level, which require different demands of play. Such information could be particularly useful in determining the progressive behaviours and skills needed to advance from youth to the adult level of competition.

2.4 Fatigue development during and after team handball activity

2.4.1 Changes in high-intensity activities during match play

The development of fatigue over the course of matches remains a pertinent issue affecting team success. Fatigue is defined as an inability to sustain the required work-rate, manifesting in a reduced generation of force (Hawley & Reilly, 1997). Causes of this reduction are explained by a multitude of interacting factors, encompassing physiological, perceptual-motor and cognitive influences (Bartlett, 1943). With this in mind, fatigue has the potential to limit performance during matches, which require the athlete to maintain high physical, technical, decision-making and psychological skills (Knicker *et al*., 2011). Time-motion video analysis (TMA) has been widely used as an objective method to detect fatigue, revealing altered work rate, technique, and/ or occurrence of errors over the course of a match (Knicker *et al*., 2011). In particular, researchers have recognised a reduction in the distance covered in high-intensity running throughout a competitive match as a key indicator of fatigue (Michalsik *et al*., 2013a; Mohr *et al*., 2003).

To the best of the author's knowledge, only three studies have used TMA to investigate the impact of fatigue during team handball matches (Michalsik *et al*., 2013a, Pόvoas *et al*., 2012, Chelly *et al*., 2011). Most recently, Michalsik *et al*. (2013a) reported a 16.2% reduction in the amount of high-intensity running performed in the first (155.3 ± 47.6 m) compared to the second half (130.4 ± 38.4 m; $P < 0.05$; $ES = 0.58$) in 82 elite Danish players analysed over 62 matches. Notably, Michalsik and colleagues (2012) monitored players competing for >70% of matches, which excludes players competing for shorter time periods. Pόvoas *et al*. (2012) also reported a decrease in the percentage of time spent fast running (2.5% *cf.* 1.9%, $P < 0.05$) when Portuguese players were monitored over 10 official matches. The same study also reported no changes in other high-intensity activities (sprint and/ or high-intensity sideways movements). Small changes in in high-intensity activities in this study could be due to methodological issues; namely monitoring of positional movements for entire matches rather than individual players. Due to the continuous rotation of players on and off the court in a team handball match, this design does not provide information to determine how players fatigue over the course of a match. Nevertheless, this study did report declines in the frequency of stops, changes of direction, and one-on-one situations. It also reported lower HR during the second half (effective HR: 160 ± 16.7 *cf.* 153 ± 18.7 $b \cdot min^{-1}$), with elite males spending a lower percentage of time in activities >80% HR_{max}, and more time in low-intensity activities (Póvoas *et al*., 2012). Somewhat larger reductions were evident in youth players competing in 2 by 25 min halves (Chelly *et al*., 2011), showing decreases of 46% in distance covered during sprinting (63.6 ± 7.3 m *cf.* 34.6 ± 6.3 m), 27% in high-intensity running (94.3 ± 72.9 m *cf.* 69.0 ± 12.7 m), as well as a 7.4% decrease in total distance covered from the first to second half. Frequency of handball specific technical actions, duration of run bouts and HR all decreased over the match (83 *cf.* 87% HR_{max}), with players spending more time at intensities between 81 – 85% HR_{max}, and less time >85% HR_{max}, demonstrating a decline in work-rate during the second half. Mean blood lactate concentration was also higher immediately after the first than after the second half of game (9.7 ± 1.1 vs. 8.33 ± 0.93 $mmol \cdot l^{-1}$), confirming an inability to maintain high-intensity work, and the potential benefit of lactic-acid tolerance training to improve performance (Chelly *et al*., 2011; Souhail *et al*., 2010). Players in the study by Chelly and colleagues (2011) competed for the full 25 min period, making it unsurprising that fatigue occurred to the greatest extent of all studies. As players are unlikely to play full matches, the applicability of these findings to aid understanding of the physiological demands and fatigue response during competition is limited.

2.4.2 Neuromuscular responses to team handball competition

Reductions in neuromuscular performance indicate the extent to which fatigue has occurred during or after competition. Impairment of muscle contractile function can lead to decrements in neuromuscular force and compromise the quality of movement patterns during match activities (Ronglan *et al*., 2006). By identifying the impact of matches on markers of neuromuscular function, coaches can be better informed to develop strategies to reduce fatigue, enhance recovery, and maximise overall team performance.

Ronglan *et al*. (2006) investigating the effect of cumulative training and matches, reported no difference in 20 m sprint performance on the first (3.17 ± 0.03 s) a and second day (3.15 ± 0.03 s) of an international tournament. This suggests that elite players are able to cope with the physiological demands of a single handball match. However, it is evident that a larger sample size, alongside other indicators of handball-specific performance are needed to gain a more comprehensive view of how elite team handball matches influence neuromuscular function.

Other research assessing neuromuscular responses in team handball have used simulation protocols, which enable players to undergo a series of match-based activities to replicate a real-match situation. Such protocols allow external factors of competition to be standardised, enabling researchers to investigate the impact of competition on a particular variable, such as sprinting, jumping, or throwing (Sirotic & Coutts, 2007). Using a handball-specific protocol, Thorlund *et al*. (2008) instructed players to carry out a series of movements over seven periods of 7 min (walking, jogging, fast running, sprinting, backwards running, repeated anterior-posterior movements, sideways movements, side-cuttings, and jump shots including acceleration), lasting for ~50 min in total. Reductions in lower body function were evidenced via height (5.2%) and rate of force production (~30%) during jumping. Maximal voluntary contraction was also lower in the quadriceps (11.3%) and hamstrings (9.8%), with rate of force development being ~16 - 21% lower. These results corroborate findings from a generic 'team game circuit' showing declines in repeated 15 m sprint and jump performance after completing four circuits of 15 min (Singh *et al*., 2010). These findings suggest the potential for matches to negatively influence both the rate and maximal force production, which could have negative consequences on many integral team handball acceleration movements (e.g sprinting, side-cutting, blocking, body contact). However, these protocols are limited by the much greater total distance covered by players (6,527 m and 5,400 m) compared to real-match situations (~3,000 to ~4,000, Luig *et al*., 2008; Michalsik *et al*., 2013a, respectively), thus potentially imposing a greater physiological load and causing a more detrimental decline in performance. Unfortunately, detailed analysis of the period when fatigue was manifested was not reported, thus making it difficult to interpret how long players competed for before reductions in neuromuscular performance occurred.

The effect of fatigue on throwing performance has shown decreases in throwing accuracy but not velocity under conditions of simulated fatigue (Zapartidis *et al*., 2010; Zapartidis *et al*., 2007). Using a handball-specific protocol with shots every 10 min, Zapartidis *et al*. (2007) reported a gradual decline in throwing accuracy over time, while throwing velocity and rotational strength of the shoulder were unaffected. The same research group also reported similar findings in experienced female handball players, with progressive declines in accuracy being most substantial in the final 10 min of the protocol (Zapartidis *et al*., 2010). Moreover, timing of movement velocities of the elbow and shoulder were significantly different to baseline in the last 10 min of each 30 min half. This suggested that neuromuscular fatigue caused changes in coordination of the movement pattern, leading to an interference with placement of ball direction (Zapartidis *et al*., 2010). Although these studies are useful for gaining a better understanding of how team handball demands influence throwing ability, shortcomings include an over-estimation of distance covered (5,500 m), and the use of a push-up performed eight times during each 10 min circuit to replicate body contact. While this movement may well increase the physiological load, it is arguable whether this method is representative of the muscle trauma imposed through direct body contact between two individuals during a handball match. Accordingly, protocols using a better representation of one-on-one situations could be useful to gain a greater understanding into the fatigue response during throwing and other key actions.

2.4.3 Neuromuscular responses to multiple training sessions and matches

Decrements in performance immediately after matches often take days to return to baseline values, thus making scheduling of future training and matches problematic for players and coaches (Andersson *et al*., 2008; Dawson *et al*., 2005). It is well known that World Championships and other major competitions usually take place within a very short time period, often requiring players to compete in six to eight, or an even greater number of matches in ten or fourteen days (Gruić *et al*., 2006). The consequences of subjecting players to subsequent bouts of loading when they are not sufficiently recovered from a previous exercise bout can cause a breakdown of physiological and psychological condition (Bishop *et al*., 2008), leading to negative performance consequences and increased risk of injury (Reilly & Ekblom, 2004). Therefore, it is important that coaches are provided with information on the time-course of player recovery after matches, in addition to the potential impact of a congested training and match schedule on parameters of neuromuscular performance. Only then can coaches make informed decisions regarding subsequent training and strategies to optimise player recovery (Andersson *et al*., 2008).

Research addressing the fatigue response of team handball players to multiple matches and training is scarce. Ronglan *et al*. (2006) reported decreases in 20 m sprint (4%) and CMJ (7%) performance of national female Norwegian handball players, when competing in three matches over the course of three days. While changes in CMJ performance were only reported prior to match three, more intricate analysis of sprint performance revealed that all pre-match sprint values were significantly different to baseline (3.10 ± 0.03 s) on days one

(3.17 ± 0.03 s), two (3.15 ± 0.03 s) and three (3.19 ± 0.02 s) respectively. Although there was no difference in sprinting performance before and after the match on day one, post-match scores on day two were significantly lower (3.20 ± 0.03 s) compared to before (3.15 ± 0.03 s), while day three scores also showed a similar trend (pre: 3.19 ± 0.02 s; post: 3.21 ± 0.02 s). Similar reductions in these performance measures, which also included voluntary knee extension peak torque at $60°\cdot s^{-1}$ and jump height were apparent when players were monitored over a five-day training camp (Ronglan *et al*., 2006). Such findings confirm the heightened need for recovery when training and matches occur within a short duration. Indeed, this study showed that CMJ was still impaired 48 h after a training session, highlighting that players might be required to compete in a less than optimal neuromuscular state during subsequent matches. Further studies are needed to investigate the neuromuscular responses to intense scheduling at training camps and international tournaments. This information is essential for coaches in order to establish effective strategies to better manage the player recovery process.

These results highlight the need for team handball coaches to monitor neuromuscular function in the days after a match, particularly when match schedules are congested. Doing so would help to inform decisions on playing time and team selection for subsequent matches. Furthermore, effective utilisation of recovery strategies and manipulation of training load between matches would help to restore or elevate the physiological state ready for the next match (Rollo *et al*., 2014; McLean *et al*., 2010).

2.5 Perceptual responses to multiple training and matches

2.5.1 Mood disturbances and well-being

The psychological response of an athlete experiencing large physical workloads that are typical of tournament scenarios can be a key influential factor to determine success (Matthys *et al*., 2011). Insufficient recovery coupled with increased training load can manifest in pronounced stress on psychological as well as aforementioned physiological systems (Kellmann, 2010). The need for optimal psychological and emotional functioning during training and performance has led to the development of a variety of instruments to monitor how players respond to this demand. These tools aim to gain information on an individual's mood, their need for recovery, and their current life circumstances (Kellman, 2010). Most widely used psychological questionnaires include the Profile of Mood States (POMS, McNair *et al*., 1971, 1992), the Recovery-Stress Questionnaire in Sport (REST-Q Sport; Kellman & Kallus, 2001) and customised well-being questionnaires (e.g. McLean *et al*., 2010). Administering questionnaires is favoured by many as they provide a simple and cost-effective monitoring tool for coaches to use on a regular basis throughout a team sport season (McLean *et al*., 2010).

Detrimental psychological responses have been reported in athletes exposed to increased training loads over short periods of time (Hadala *et al*., 2010; Elloumi *et al*., 2008; Halson *et al*., 2002; O'Connor *et al*., 1991). Mood disturbance in athletes during intensified training appear alongside increases in muscle soreness, increased rating of perceived exertion (RPE), increased sensations of fatigue and decreased performance (Halson *et al*., 2002; O'Connor *et al*., 1991). While an increased training load causes mood disturbances in a dose-dependent relationship, psychological well-being returns to normal when training load is reduced (Coutts & Reaburn, 2008; Coutts *et al*., 2007; Halson *et al*., 2002).

In the only team handball study to assess the psychological responses to training, Bresciani *et al*. (2010) demonstrated that well-trained Spanish male players had higher social stress when training load was at its highest during a season (Bresciani *et al*., 2010). However, the same study did not find any other significant differences over the course of the season in total mood disturbance (POMS, McNair *et al*., 1971), or total scores for stress, recovery, or recovery-stress states (RESTQ-Sport, Kellman & Kallus, 2001). Therefore, with the exception of social stress, this suggests that players were able to cope with the training and match loads imposed on them throughout the season. The successful psychological abilities of these players is likely due to their high level of experience at this competitive level (~11 years), enabling them to become well practiced with coping with high physical workloads and maximising between-session recovery. However, it was usual for players to compete in one match per week during the competitive season, highlighting that these findings cannot be generalised to more intense periods of competitions when a large number of matches are played within a shorter time frame.

Evidence highlights the potential negative consequences experienced when athletes are unable to cope with greater training stresses as load increases. Such instances are common when athletes are exposed to training camps and international competitions, whereby psychological and physiological stressors are heightened (Gruić *et al*., 2008; Ronglan *et al*., 2006). As research has suggested that physiological and psychological processes are inter-related, monitoring psychological and emotional state could be integral to understand the changes in physiological status and subsequent performance (McLean *et al*., 2010). Therefore, regular monitoring of psychological and physiological state, particularly during periods of intense training and competition, is essential to manage the balance between training and recovery, reduce injury risk, and optimise performance (Kellman *et al*., 2010; McLean *et al*., 2010; Reilly & Ekblom, 2004). More studies, particularly assessing the impact of training load during intense competition is paramount to improve knowledge on effective player management in team handball.

2.6 Conclusions

While identification of the physical, physiological and performance characteristics of successful team handball players is emerging, analysis of youth players is particularly underdeveloped. This makes it problematic to propose strategies for talent identification and to inform training practices that maximise performance during competition. Unlike successful team handball nations, who select and train experienced players for international competition, developing nations, such as Great Britain and England select from a limited number of athletes with relatively less team handball experience. Therefore, to facilitate progression, it is essential to develop selection, training, and match preparation processes through evidenced-based investigation. Therefore, the purpose of the studies that follow is to gain a greater understanding into the characteristics of English players with the aim to improve the overall standard of team handball.

CHAPTER 3:

ANTHROPOMETRIC AND PHYSICAL PERFORMANCE CHARACTERISTICS OF TOP-ELITE, ELITE AND NON-ELITE YOUTH FEMALE TEAM HANDBALL PLAYERS

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Moss, S. L., McWhannell, N. Michalsik, L. B., & Twist, C. Assessment of anthropometric and physical performance characteristics between playing standard and position in youth female team handball players. Proceedings of the 19th Annual Congress of the European College of Sports Science. Amsterdam, 2-5 July, 2014.

Moss, S. L., McWhannell, N. Michalsik, L. B., & Twist, C. Anthropometric and physical performance characteristics of elite and non-elite youth female team handball players. In: European Handball Federation Scientific Conference (eds.). Women and handball: Scientific and Practical Approaches. Proceedings of the second International Conference on Science in Handball. Vienna. Austria. 22-23 November 2013: 96-101.

3.1 Introduction

Team handball is an intermittent team sport, characterised by high-intensity explosive movements such as sprints, jumps, throws, and physical confrontations, which are interspersed with periods of low intensity activity such as standing, walking, and jogging (Refer to Chapter 4; Michalsik *et al.*, 2013a; Michalsik at al., 2014a). Success in team handball is determined by a variety of technical and tactical, mental, anthropometric, and physical performance characteristics (Vila *et al.*, 2012). Although the measurement of technical and tactical skills are often confounded by subjectivity, assessment for anthropometric and physical profiles enable the collection of objective data, which can be used to form structured talent detection and identification programmes (Bloomfield *et al.*, 1994) and identify areas for training focus.

Information on the essential characteristics for successful team handball performance is valuable to coaches and practitioners working with developing nations, where there are a limited number of athletes to select from and the sport is not well established (Mohamed *et al.*, 2009). From a relatively unknown sport in Great Britain prior to the 2012 Olympic Games, there has been a 96% increase in affiliated club members from 2010-11 season to 2012-13 season, accompanied by an overall increase in participation at the youth level (~48%; England Handball Association, personal correspondence). However, performance at youth international standard remains poor, with youth female squads yet to qualify for any major international competition. Therefore, to maximise the potential for success, it is important for such nations to develop superior systems to identify and develop talent, which requires comprehensive and up-to-date values on elite players (Carter *et al.*, 2005).

Differences in anthropometric and performance characteristics between playing standards are widely available for male team handball players (Matthys *et al.*, 2011; Mohamed *et al.*, 2009;

Zapartidis *et al.*, 2009a; Gorostiaga *et al.*, 2005). This research has indicated that elite males encompass anthropometric and performance characteristics deemed more favourable to team handball compared to their lower standard counterparts (Mohamed *et al.*, 2009; Zapartidis *et al.*, 2005; Gorostiaga *et al.*, 2005). Such data are less prominent in females (Zapartidis *et al.*, 2009a; Granados *et al.*, 2007), making it problematic to understand the most important determinants to compete in elite standard female match-play. In particular, there is a dearth of research assessing both anthropometric and performance characteristics of youth female players of different standards. Zapartidis *et al.* (2009a) recorded better values for selected female Greek national players in ball velocity and standing long jump, but not in 30 m sprint speed, sit and reach or $\dot{V}O_{2\ max}$. Selected players were also taller, and had greater arm spans than non-selected players, but were similar in body mass, body mass index (BMI), hand length, and hand-spread. However, this study assessed very young players (~13 y) and only provides information from one nation. A deeper understanding of the differences between top-elite, elite and non-elite female team handball players would enable coaches to benchmark players and classify them more precisely in relation to the desired prototype. Such data would help determine those physically capable of achieving success in a particular sport or position within that sport (Vila *et al.*, 2012), and also help in tracking of youth players to adult competition. Accordingly, the present study aimed to examine the differences in anthropometry and performance between non-elite, elite and top-elite youth female team handball players. It was hypothesised that there would be differences in anthropometry and performance characteristics between all standards, with top-elite fairing most favourably, followed by elite and then non-elite players.

3.2 Methods

3.2.1 Participants

In total, 120 female youth team handball players (16.1 ± 1.3 y) were recruited to take part in the investigation, including both outfield players and goalkeepers. This comprised 47 players from Great Britain who were classified as non-elite (15.7 ± 1.3 y, stature: 165.4 ± 5.8 cm, body mass: 61.1 ± 7.8 kg), 44 players from high standard European league club teams who were classified as elite (15.8 ± 1.3 y, stature: 169.3 ± 6.3 cm, body mass: 64.0 ± 9.4 kg), and 29 European international players who were classified as top-elite (17.1 ± 1.1 y, stature: 176.3 ± 6.6 cm, body mass: 71.8 ± 8.6 kg). Players from elite and top-elite groups were from nations that consistently placed within the top five teams at the European Youth Championship and the Youth World Championship, whereas Great Britain or England had never qualified to compete.

Non-elite players all competed for their club (*n*=47), of whom 29 represented Great Britain and/ or England (U16 – U19). For the elite players, 27 competed in the highest league for their age category (Denmark: Liga and qualified for the Danish championship; Norway: Bring series), and 17 competed in the second highest league (Spanish Catalan league). All top-elite players competed for their club and performed at international level (U17 – U19). Top-elite U17/ U19 Danish teams were current European Championship and World Championship holders, respectively. All measurements were taken in-season between December 2012 and June 2013. Non-elite and elite players were tested between December and May during their domestic league competition period, while top-elite players were tested in June during their international season. After completion of anthropometric measurements, all performance tests were completed in one day in the same order in order to minimize disruption to training practices. All players provided written informed consent and the study was approved by the institute's Research Ethics Committee and was carried out in accordance with the declaration of Helsinki.

3.2.2 Procedures

3.2.2.1 Anthropometric characteristics

Standing stature (Seca, Leicester Height Measure, Hamburg, Germany), body mass (Tanita, BWB-800, Tanita Corporation, Tokyo, Japan), eight skinfolds (Harpenden, British Indicators, Burgess Hill, UK), five girths (Lufkin Executive Thinline, W606PM, USA) and two breadths (Roscraft Campbell 10, Canada), were measured according to the protocols of the International Society for the Advancement of Kinanthropometry (ISAK; Marfell-Jones *et al.*, 2006). Skinfold sites were landmarked at: the triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, and medial calf on the right side of the participant's body. All sites were then measured using callipers with 10 $g \cdot mm^{-2}$ constant pressure. Girths were measured for the forearm (relaxed and flexed/ tensed), waist, hips (gluteal), and calf, and breadths at the humerus and femur (distance between the medial and lateral epicondyles). Each measure was taken two or three times, (Stewart *et al.*, 2011) by the same Level 1 accredited investigator. Technical error of measurement was <3% for skinfolds, and <1% for breadths and girths, which were deemed acceptable by ISAK standards (Carter, 2002). The sum of six and eight skinfolds was calculated and waist-to-hip ratio was determined by dividing the waist girth by the gluteal girth. Percentage body fat was derived from skinfolds using the equation by Durnin and Wormersley (1974), which was then used to calculate fat mass and lean body mass. Somatotypes were determined using methods previously described by Carter and Heath (1990).

3.2.2.2 Physical performance tests

Prior to test commencement, coaches from each team were provided with testing procedures and were asked to lead a 20 min warm-up including running, sprinting, agility and throwing drills to ensure adequate player preparation. After familiarization to the procedures, all participants completed the same tests in the following order with sufficient recovery between each: maximal counter-movement jump (CMJ), 20 m sprint with 10 m split, throwing velocity, repeated shuttle sprint and jump ability (RSSJA) and the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1).

Participants began the CMJ (coefficient of variation [CV] = 4.30%) in an upright position, with the hands placed on the hips to minimize any influence from the arms. Participants flexed at the knee to a self-selected depth and then jumped for maximal height. Participants were observed throughout to ensure that landing and take-off position were the same. Jumps that did not meet the stated criteria were not recorded, and in such cases the participant was asked to complete a new jump. Jump height was recorded from flight time using the equation of 9.81 x flight time^2 /8 (Bosco *et al.*, 1983) measured using an infrared timing system (Optojump, Microgate S.r.l., Bolzano, Italy) interfaced with a laptop. Peak power was calculated using the formula: CMJ (W) = (60.7 x height [cm]) + (45.3 x body mass [kg]) – 2055. This equation has been used previously (Buchheit *et al.*, 2010), and provides an accurate estimation of peak power from jump height (Sayers *et al.*, 1999). Participants performed one practice jump followed by two test jumps with the highest jump height recorded for analysis.

Sprint performance over 20 m (CV = 1.36%) was measured using electronic timing gates (Brower Timing Systems, Microgate, Bolzano, Italy) placed at 0, 10 and 20 m in an indoor sports hall. The use of 10 m split time was based on a similar protocol (Ingesbrigtsen, *et al.*, 2013). Players began from a stationary standing start, with their foot directly behind the 0 m line (without touching the line with their foot) and began when ready. Participants performed one practice sprint and two test sprints, with ~2 minutes recovery between each sprint. The best 20 m sprint time was recorded for analysis.

Throwing velocity ($km \cdot h^{-1}$) was assessed using a radar gun (Bushnell Sports Radar Gun, 101911, Kansas City, USA), placed 1 m to the side of the goal post, and perpendicular to the player. Players applied resin as desired to a size 2 handball, and completed maximal effort throws in three conditions without a goalkeeper, based on procedures conducted by Vila and colleagues (2012): (a) standing set throw from 7 m penalty line (i.e. a penalty throw), (b) set throw with 3-step run-up from 9 m, (c) jump throw with 3-step run-up from 9 m. Each participant completed one practice throw and two test throws without a goalkeeper, and the fastest throw was recorded for analysis. Players received ~2 min recovery time between conditions with only throws on target selected for analysis (CVs = 3.95%, 3.08% and 4.01% for throw types a, b and c, respectively).

The Repeated Shuttle Sprint and Jump Ability Test (RSSJA; Buchheit *et al.*, 2010) comprised six maximal 2 × 12.5 m out-and-back shuttle sprints (~5 s) starting every 25 s. Participants had ~20 s recovery between sprints, where they were required to decelerate, perform a CMJ, and then an active recovery (covering 36 m ≈ running at 2.1 $m \cdot s^{-1}$). Averages were calculated for CMJ variables, and times for 10 m, agility (the time between 10 m, and the 2 x 2.5 m turn-around), and total 25 m (CVs = 1.0%, 2.9% and 1.5% for repeated sprints, CMJ height and CMJ power, respectively, Buchheit *et al.*, 2010).

The Yo-Yo IR1-test (Krustrup *et al.*, 2003) required the participant to perform of 2 x 20 m shuttle running bouts, interspersed with 10 seconds recovery at progressive speeds dictated by a pre-recoded audio signal. The final score was recorded as the total distance covered after the second failed attempt to complete the shuttle running bout in the required time. All participants were familiar with this test as part of their normal fitness testing procedures.

3.2.3 Statistical analysis

Data are expressed as mean ± SD. Assumptions of normal distribution and homogeneity were checked using Kolmogrov Smirnoff and Levene tests. A one-way analysis of covariance (ANCOVA) was used to examine for any differences between non-elite, elite and top-elite players in all variables. Age was included as the covariate in order to control for its potential contribution on observed results. All significant effects were followed up with Bonferroni *post-hoc* tests. Effect sizes and magnitude-based inferences (Batterham & Hopkins, 2006), were also calculated for all variables. Based on the 90% confidence limits, threshold probabilities for a substantial effect were: 0.5% most unlikely, 0.5–5% very unlikely, 5–25% unlikely, 25–75% possibly, 75–95% likely, 95–99.5% very likely, >99.5% most likely. The threshold for the smallest important change was determined as the within-participant standard deviation (s) x 0.2 (small effect), with 0.6, 1.2, and >2.0 representing a moderate, large, and very large effect, respectively. Effects with confidence limits across a likely small positive or negative change were deemed unclear (Hopkins *et al.*, 2006). A predesigned spreadsheet (Hopkins, 2006) was used for all calculations. Relationships between anthropometric characteristics and markers of performance were conducted using the Pearson-moment correlation (*r*). Analyses were performed using Predictive Analytics Software (PASW) Statistics v.18 (SPSS Inc., Chicago, IL), with the alpha level set at $P < 0.05$.

3.3 Results

Analysis revealed differences between standard in a variety of anthropometric (Table 3.1) and performance (Table 3.2) characteristics. Top-elite players were taller and had higher body mass than both elite and non-elite counterparts (both $P < 0.001$), and elite were taller than non-elite players ($P = 0.01$). This was accompanied by greater lean body mass in top-elite compared to elite ($P = 0.01$) and non-elite players ($P < 0.001$). Top-elite players also had greater girth measurements for relaxed arm, calf girth, and humerus breadth than both elite and non-elite players (all $P < 0.05$), and greater flexed arm ($P < 0.001$) and gluteal girths ($P = 0.02$) than non-elite players.

There were no differences in the total sum of six or eight skinfolds, fat mass, or waist-to-hip ratio between standard (all $P > 0.05$). Somatotype profile rating (endomorphy-mesomorphy-ectomorphy) for non-elite (4.0 – 3.4 – 2.3) and elite (3.8 – 3.3 – 2.6) players was mesomorphic endomorph, whereas top-elite players were classified as central (3.3 – 3.2 – 2.6). In all cases, endomorphy was the most dominant component, with ectomorphy being the least dominant. There was a significant age effect for relaxed arm girth ($P = 0.04$) and flexed arm girth ($P = 0.01$) although differences between standard were apparent independent of this covariate ($P = 0.01$, $P = 0.003$, respectively).

Top-elite players out-performed both elite and non-elite players in 20 m sprint, CMJ, all throwing velocity tests, the Yo-Yo IR1 and all variables on the RSSJA test (all $P < 0.05$), excluding average time to complete 10 m ($P = 0.14$). Elite players were only better than non-elite players in throwing velocity ($P < 0.001$). There was a significant age effect for all performance variables ($P < 0.05$) with the exception of agility ($P = 0.06$). However, differences between standard were independent of this covariate in all performance tests (P <

0.05), excluding 10 m maximal sprint (P = 0.20) and 10 m average sprint during the RSSJA (P = 0.14).

Table 3.1: Anthropometric characteristics and comparison of non-elite, elite and top-elite youth players

	Non-elite (*n*= 44)	**Elite (*n*= 44)**	**Top-elite (*n*= 29)**	**Difference ± 90% CL**	***Descriptor***	
Variable				**NE vs. E**	**NE vs. TE**	**E vs. TE**
Body mass (kg)	61.1 ± 7.8 [TE]	64.0 ± 9.4 [TE]	71.8 ± 8.6	- 2.9 (± 3.1)	- 10.1 (± 3.2)	- 7.2 (± 3.5)
				Likely small ↓	*Most likely moderate* ↓	*Very likely moderate* ↓
Stature (cm)	165.4 ± 5.8 [TE, E]	169.3 ± 6.3 [TE]	176.3 ± 6.6	- 3.9 (± 2.1)	- 10.8 (± 2.6)	- 6.9 (± 2.7)
				Very likely large ↓	*Most likely large* ↓	*Most likely moderate* ↓
Fat mass (kg)	11.9 ± 3.56	12.8 ± 3.91	12.9 ± 2.83	- 0.8 (± 1.3)	- 0.9 (± 1.2)	0.1 (± 1.3)
				Possibly small ↓	*Possibly small* ↓	*Unclear*
Lean mass (kg)	49.0 ± 5.39 [TE]	52.0 ± 6.77 [TE]	57.8 ± 5.99	- 3.1 (± 2.2)	- 9.1 (± 2.4)	- 5.9 (± 2.6)
				Likely small ↓	*Most likely large* ↓	*Most likely moderate* ↓
Skinfolds (mm)						
Tricep	15.1 ± 4.1	15.8 ± 4.17	14.2 ± 2.57	- 0.7 (± 1.5)	0.8 (± 1.3)	1.6 (± 1.3)
				Possibly trivial ↓	*Possibly trivial* ↑	*Likely small* ↑
Subscapular	11.7 ± 4.16	10.5 ± 3.52	9.4 ± 2.99	1.2 (± 1.4)	2.5 (± 1.4)	1.2 (± 1.3)
				Possibly small ↑	*Very likely moderate* ↑	*Likely small* ↑
Bicep	7.4 ± 2.14	7.0 ± 2.25	5.8 ± 1.77	0.4 (± 0.8)	-.7 (± 0.8)	1.3 (± 0.8)
				Possibly trivial ↑	*Most likely moderate* ↑	*Very likely moderate* ↑
Iliac crest	16.5 ± 4.19	17.0 ± 5.10	15.1 ± 4.45	- 0.6 (± 1.7)	1.8 (± 1.6)	2.4 (± 1.8)
				Unclear	*Likely small* ↑	*Likely small* ↑
Supraspinale	12.1 ± 4.15	11.6 ± 4.60	10.5 ± 3.70	-0.4 (± 1.6)	1.7 (± 1.6)	1.3 (± 1.6)
				Unclear	*Likely small* ↑	*Possibly small* ↑
Abdominal	17.7 ± 4.84 [E]	16.5 ± 5.27	14.1 ± 4.08	1.2 (± 1.8)	3.7 (± 1.8)	2.5 (± 1.8)
				Possibly small ↑	*Very likely small* ↑	*Likely small* ↑

	Non-elite	Elite	Top-elite	Difference ± 90% CL		
	(*n*= 44)	(*n*= 44)	(*n*= 29)	*Descriptor*		
Variable				**NE vs. E**	**NE vs. TE**	**E vs. TE**
Front thigh	22.7 ± 5.40	21.7 ± 4.35	20.0 ± 4.39	0.9 (± 1.7)	2.6 (± 1.9)	1.6 (± 1.8)
				Possibly trivial ↑	*Likely small* ↑	*Likely small* ↑
Medial calf	15.6 ± 4.46	16.1 ± 4.27	14.7 ± 3.40	- 0.5 (± 1.5)	0.9 (± 1.6)	1.4 (± 1.5)
				Unclear	*Possibly small* ↑	*Possibly small* ↑
Sum of 6	94.8 ± 21.59	92.2 ± 22.48	82.9 ± 16.51	2.6 (± 7.8)	12.2 (± 7.6)	9.7 (± 7.7)
				Unclear	*Very likely small* ↑	*Likely small* ↑
Sum of 8	118.7 ± 26.53	116.3 ± 28.70	103.7 ± 21.27	2.4 (± 9.8)	15.8 (± 9.4)	13.4 (± 9.8)
				Unclear	*Very likely moderate* ↑	*Likely small* ↑
Girths (cm)						
Arm relaxed	26.3 ± 2.13 [TE]	27.1 ± 2.83 [TE]	28.8 ± 2.0	- 0.8 (± 0.9)	- 2.4 (± 0.8)	- 1.6 (± 0.9)
				Possibly small ↓	*Most likely moderate* ↓	*Very likely moderate* ↓
Arm flexed	27.3 ± 2.23 [TE, E]	28.7 ± 2.42 [TE]	30.3 ± 1.98	- 1.4 (± 0.8)	- 2.9 (± 0.8)	- 1.6 (± 0.9)
				Very likely small ↓	*Most likely moderate* ↓	*Very likely moderate* ↓
Waist	70.1 ± 5.53 [TE]	71.9 ± 5.33	74.6 ± 4.61	- 1.7 (± 1.9)	- 4.2 (± 2.0)	- 2.5 (± 1.9)
				Possibly small ↓	*Very likely moderate* ↓	*Likely small* ↓
Gluteal	95.9 ± 5.56 [TE]	98.2 ± 6.86	101.2 ± 5.29	- 2.3 (± 2.2)	- 5.1 (± 2.2)	- 2.9 (± 2.4)
				Likely small ↓	*Most likely moderate* ↓	*Likely small* ↓
Calf	35.0 ± 2.28 [TE]	35.3 ± 2.28 [TE]	36.9 ± 2.19	- 0.3 (± 0.8)	- 1.7 (± 0.9)	- 1.5 (± 0.9)
				Unclear	*Very likely moderate* ↓	*Very likely moderate* ↓
Waist-to-hip ratio	0.7 ± 0.04	0.7 ± 0.02	0.7 ± 0.03	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)
				Unclear	*Unclear*	*Unclear*

	Non-elite (*n*= 44)	Elite (*n*= 44)	Top-elite (*n*= 29)	Difference ± 90% CL *Descriptor*		
				NE vs. E	NE vs. TE	E vs. TE
Breaths (cm)						
Humerus	6.4 ± 0.28 [TE]	6.4 ± 0.28 [TE]	6.7 ± 0.34	0.1 (± 0.1)	- 0.3 (± 0.1)	- 0.2 (± 0.1)
				Possibly small ↓	*Most likely moderate* ↓	*Very likely moderate* ↓
Femur	8.0 ± 0.41	8.2 ± 0.46	8.2 ± 0.36	- 0.2 (± 0.2)	- 0.1 (± 0.2)	0.1 (± 0.2)
				Likely small ↓	*Possibly small* ↓	*Unclear*

Note: Non-elite, E = Elite; TE = Top-elite. Significant difference (P < 0.05) between groups indicated by TE, E. Threshold probabilities for a substantial effect were: 0.5% most unlikely, 0.5–5% very unlikely, 5–25% unlikely, 25–75% possibly, 75–95% likely, 95–99.5% very likely, >99.5% most likely. Thresholds for the magnitude of the observed change in each dependent variable were determined as the within-participant s x 0.3, 0.9 and 1.6 for a small, moderate and large effect, respectively. Cohen's *d* effect sizes were classified as: trivial <0.2, small 0.2-0.6, moderate 0.6–1.2, large 1.2–2.0, and very large >2.0 (Hopkins, 2006).

Table 3.2: Performance characteristics and comparison of non-elite, elite and top-elite players

	Non-elite (***n***= 47)	Elite (***n***= 37)	Top-elite (***n***= 29)	Difference ± 90% CL *Descriptor*		
Variable				**NE vs. E**	**NE vs. TE**	**E vs. TE**
Sprints and CMJ						
10 m sprint (s)	2.10 ± 0.13[TE]	2.08 ± 0.75[TE]	2.00 ± 0.68	0.0 (± 0.0) *Possibly small ↑*	0.1 (± 0.0) *Most likely moderate ↑*	0.1 (± 0.0) *Most likely mod ↑*
20 m sprint (s)	3.65 ± 0.23[TE]	3.58 ± 0.21[TE]	3.41 ± 0.12	0.1 (± 0.1) *Possibly small ↑*	0.2 (± 0.1) *Most likely moderate ↑*	0.2 (± 0.1) *Most likely moderate ↑*
CMJ height (cm)	28.2 ± 5.42[TE]	26.5 ± 4.57[TE]	33.5 ± 4.06	1.7 (± 1.8) *Possibly small ↑*	- 5.3 (± 1.8) *Most likely moderate ↓*	- 4.3 (± 2.1) *Very likely moderate ↓*
CMJ power (W)	2302.6 ± 552.01[TE]	2442.5 ± 470.54[TE]	3231.5 ± 460.0	- 139.9 (± 192.9) *Possibly small ↓*	- 928.8 (± 202.5) *Most likely large ↓*	- 788.9 (± 192.5) *Most likely large ↓*
Throwing velocity *($km \cdot h^{-1}$)*						
Standing set-throw	55.2 ± 7.87[TE, E]	65.4 ± 7.64[TE]	80.9 ± 7.10	- 5.7 (± 1.8) *Most likely moderate ↓*	- 15.4 (± 1.8) *Most likely large ↓*	- 9.7 (± 1.9) *Most likely large ↓*
Set-throw 3-step run-up	59.1 ± 8.74[TE, E]	72.1 ± 7.34[TE]	83.2 ± 5.78	- 7.4 (± 1.8) *Most likely large ↓*	- 13.1 (± 1.9) *Most likely large ↓*	- 5.7 (± 1.9) *Most likely moderate ↓*
Jump throw 3-step run-up	59.9 ± 8.50[TE, E]	71.0 ± 8.16[TE]	80.6 ± 4.73	- 6.9 (± 1.9) *Most likely moderate ↓*	- 12.9 (± 1.6) *Most likely large ↓*	- 6.0 (± 1.7) *Most likely moderate ↓*

	Non-elite (*n*= 47)	Elite (*n*= 37)	Top-elite (*n*= 29)	Difference ± 90% CL *Descriptor*		
				NE vs. E	NE vs. TE	E vs. TE
Intermittent endurance						
Yo-Yo IR1 distance (m)	906 ± 324[TE]	935 ± 394[TE]	1663 ± 327	- 28.9 (± 137.7) *Unclear*	- 757.1 (± 128.7) *Most likely large* ↓	- 728.2 (± 880) *Most likely large* ↓
RSSJA						
10 m average (s)	2.42 ± 0.15[TE]	2.38 ± 0.13[TE]	2.30 ± 0.08	0.0 (± 0.1) *Possibly small* ↑	0.1 (± 0.0) *Most likely moderate* ↑	0.1 (± 0.0) *Very likely moderate* ↑
Agility average (s)	1.56 ± 0.27[TE]	1.58 ± 0.22[TE]	1.15 ± 0.24	- 0.0 (± 0.1) *Unclear*	0.4 (± 0.1) *Most likely large* ↑	0.4 (± 0.1) *Most likely large* ↑
25 m average (s)	6.23 ± 0.33[TE]	6.17 ± 0.34[TE]	5.69 ± 0.21	0.1 (± 0.1) *Possibly trivial* ↑	0.5 (± 0.1) *Most likely large* ↑	0.5 (± 0.1) *Most likely large* ↑
Average CMJ (cm)	21.1 ± 5.42[TE]	21.6 ± 4.27[TE]	28.3 ± 3.33	- 0.5 (± 1.7) *Unclear*	- 7.2 (± 1.6) *Most likely large* ↓	- 6.7 (± 1.6) *Most likely large* ↓
CMJ average power (W)	2302.6 ± 552.01[E]	2442.5 ± 470.54[E]	2785.1 ± 540.50	- 771.1 (± 205.3) *Unclear*	- 529.8 (± 309.4) *Very likely moderate* ↓	- 452.7 (± 320.9) *Very likely moderate* ↓

***Note*:** NE = Non-elite, E = Elite; TE = Top-elite. Significant difference ($P < 0.05$) between groups indicated by TE, E . Threshold probabilities for a substantial effect were: 0.5% most unlikely, 0.5–5% very unlikely, 5–25% unlikely, 25–75% possibly, 75–95% likely, 95–99.5% very likely, >99.5% most likely. Thresholds for the magnitude of the observed change in each dependent variable were determined as the within-participant s x 0.3, 0.9 and 1.6 for a small, moderate and large effect, respectively. Cohen's d effect sizes were classified as: trivial <0.2, small 0.2-0.6, moderate 0.6–1.2, large 1.2–2.0, and very large >2.0 (Hopkins, 2006).

Correlational analysis revealed that stature was related to a large number of performance variables, including 20 m sprint (*r*= -0.264, *P* = 0.007), average 25 m repeated sprint (*r*= -0.30, *P* = 0.002) Yo-Yo IR1 (*r*= 0.365, *P* < 0.001), as well as for all associated CMJ variables (*r*= 0.33 - 0.69, all *P* < 0.001), and velocity for all types of shot (*r*= 0.56 - 0.65, all *P* < 0.001). Body mass was positively correlated to maximal and average power for CMJ (*r*= 0.77, *r*= 0.69, both *P* < 0.001), and was related to velocity for all types of shot (*r*= 0.39 - 0.49, all *P* < 0.001). Results indicate the benefits of greater stature and body mass on a variety of performance makers.

The total sum of skinfolds showed relationships with sprint performance at both 10 m and 20 m (*r*= 0.42 – 0.50, both *P* < 0.001), and for average 25 m repeated efforts (*r*= 0.54, *P* < 0.001), indicating that higher skinfold values were associated with slower times. A similar pattern was also apparent for the Yo-Yo IR1 test (*r*= 0.49, *P* < 0.001). Higher skinfold values were found to negatively affect both maximal and average CMJ height (*r*= -0.559, *r*= -0.57) as well as shooting velocity for standing set shot (*r*= -0.29, *P* = 0.002), set shot with 3-step run-up (*r*= -0.29, *P* = 0.003) and jump shot with 3-step run-up (*r* = -0.34, *P* < 0.001).

Gluteal girths had an overall moderate effect on power parameters for CMJ (*r*= 0.55 – 0.60, *P* < 0.001), and shooting velocity (penalty: *r*= 0.33, *P* = 0.001; running: *r*= 0.33, *P* = 0.001, jumping: *r*= 0.23, *P* = 0.02). Similar results were also found for calf girth and CMJ power parameters (*r*= 0.60 – 0.65, both *P* < 0.001), and shooting velocity (*r*= 0.35 - 0.41, all *P* < 0.001), indicating the positive contribution of these characteristics to performance.

3.4 Discussion

This is the first study to include detailed analysis on both anthropometric and performance characteristics on a large sample of female players representing three standards of team handball performance. These findings reveal different anthropometric and performance profiles between youth top-elite international compared to both youth elite and non-elite female team handball players, and highlight that youth elite and non-elite players differ only in few characteristics. This study improves understanding of the quintessential characteristics needed to achieve excellence so that selection processes can be modelled accordingly.

3.4.1 Anthropometric characteristics

Anthropometric data revealed that youth top-elite players were on average 11 cm taller and 11 kg heavier than non-elite players, and 7 cm taller and 8 kg heavier than elite players. These findings are similar to differences reported between standard in youth (Zapartidis *et al.*, 2009a), and female adults (Granados *et al.*, 2007). Youth top-elite players also had greater girth and breadth measurements and higher overall lean mass than their elite and non-elite counterparts, which may indicate more developed musculature and skeletal robustness (Bourgois *et al.*, 2001). Although youth top-elite players were heavier with similar body fat compared to non-elite and elite players, they possessed more lean muscle mass. Such findings re-affirm those of other studies assessing elite and non-elite adult female (Granados *et al.*, 2007) and male players (Gorostiaga *et al.*, 2005). Collectively, the anthropometric data reveal that above average stature and higher body mass are key physical requisites for elite female handball players. This is confirmed by the correlations observed between anthropometric and performance characteristics, which reinforces the influence of these physical attributes on a handball player's ability to perform game-specific actions**.** It must also be acknowledged that the selection of more biologically mature players at the elite level could partly explain the differences in stature and body mass between standards. Indeed, the British non-elite players from this study had similar statures to the English average for 16 - 24 years (1.64 m, Health

Survey for England, 2010), which is in contrast to elite youth female team handball players who tended to be taller than their national average (Ingebrigtsen *et al.*, 2013; Zapartidis *et al.*, 2009b). Body mass for top-elite players in this study were also similar to elite adult females (67 – 70 kg, Michalsik *et al.*, 2014b; Vila *et al.*, 2012; Milanese *et al.*, 2011; Granados *et al.*, 2007), suggesting selection of youth players with a higher body mass is preferable.

3.4.2 Performance characteristics

Large differences in throwing velocity between all playing standards reaffirms that improved throwing velocity is a requirement of higher standard players (Wagner *et al.*, 2012; Wagner *et al.*, 2010; Granados *et al.*, 2007; Gorostiaga *et al.*, 2005**)**. Indeed, the final outcome of the match is dependent on the team scoring the most goals, requiring players to execute throws that often require high velocity to beat the goalkeeper (Zapartidis *et al.*, 2009c; Gorostiaga *et al.*, 2005). Overall throwing velocity was ~16 – 27% higher in youth female top-elite compared to non-elite players when taking into account all three throw types, which was substantially greater than differences reported between elite and amateur adult females (11%; Granados *et al.*, 2007). Slower throwing velocities in the non-elite youth players might be explained by allometric scaling theory (Schmidt-Nielsen, 1984). This posits that taller individuals can produce more force than smaller individuals, whereby an increase in height and subsequent cross-sectional area of the throwing arm results in an increase in force (L^3) (Van den Tillaar, 2002). As such, taller elite and top-elite players have a predisposed advantage to perform better than their shorter counterparts. As a result, lower strength and/ or power of the upper and lower body limbs, alongside poorer technique is likely to have resulted in reduced efficiency during the transfer of momentum through the pelvis and trunk to the throwing arm (Wagner *et al.*, 2010). Indeed, both strength and power (Chelly *et al.*, 2010; Marques *et al.*, 2007; Granados *et al.*, 2007) and technique (Wagner *et al.*, 2012; Wagner *et al.*, 2010; van den Tillaar & Ettema, 2007), are positively related to throwing velocity. The lower overall lean musculature and lower CMJ power observed in the non-elite and elite players support this, suggesting that players should be coached to improve muscular and technical characteristics to ensure development of this essential skill.

CMJ performance for top-elite players was ~4 - 5 cm higher than elite and non-elite players, respectively. Reasons for this might include a number of integrating factors comprising greater training focus on improving jumping performance and well-developed selection processes for top-elite players. Better performance in top-elite players is unsurprising given the important role of jumping in various aspects of the game, such as throwing and blocking (Michalsik *et al.*, 2014a; Buchheit *et al.*, 2010). Despite this, other research has failed to find differences in vertical jump performance between elite and amateur females (Granados *et al.*, 2007). It is notable that CMJ height in our youth non-elite (~28 cm) and elite (~26 cm) players was comparable to elite age-matched Norwegian players (~25 – 27 cm, Ingebrigtsen *et al.*, 2013), whereas our youth top-elite players outperformed some (~28 – 31 cm, Ronglan *et al.*, 2006), but not all (~43 cm, Vila *et al.*, 2012) elite adult players. When muscle power was estimated from jump performance, there were large differences observed when top-elite players were compared to elite and non-elite players. These findings are likely a result of overall greater body mass of elite players, alongside higher musculature, thus suggesting that measures of lower limb power are useful discriminators of performance in female youth players.

The ability to sprint and change direction at high velocities is an important determinant of team handball performance in order to reposition oneself during transition between phases of attack and defence, as well as during fast breaks and offensive breakthroughs (Michalsik *et al.*, 2013a; Michalsik *et al.*, 2014b). This study observed that 20 m maximal sprinting performance was superior in top-elite players compared to lower standard players, while no differences were observed between elite and non-elite players. Previous studies have observed differences between standard in youth males (Zapartidis *et al.*, 2009a), and adult females (Granados *et al.*, 2007). Notably, all players in our study were substantially slower (~3.65 s and ~ 3.50 s) than adult national Norwegian players over 20 m (~3.10 s), although authors do not state whether players began from a standing start or performed a prior run-up.

Top-elite players also performed better than non-elite and elite players on all variables of the RSSJA, excluding average 10 m sprint, supporting the utility of this multi-component test when assessing large numbers of players for a range of physical skills. Performance of repetitive short explosive efforts with frequent changes in direction could be crucial for match outcomes (Michalsik *et al.*, 2013a), with jumps occurring predominately after high intensity runs (Buchheit *et al.*, 2010). This study confirms the findings of Buchheit and colleagues (2010), highlighting its applicability to distinguish between playing standards for physical characteristics.

Results for the Yo-Yo IR1 demonstrated youth top-elite national players ran further distances (~1660 m) than reported for adult players from the upper half of the Danish Premier League (~1440 m, Michalsik *et al.*, 2014b). This is most likely explained by individual differences as training practices were similar between Danish adults and youth players (personal correspondence). Superior performance of top-elite players compared to non-elite and elite groups reaffirms findings from male youth team handball (Matthys *et al.*, 2011) and indicates the distance covered during the Yo-Yo IR1 distinguishes between top-elite and lower standard youth. Thus, the ability to perform repeated intense running exercise and to be able to recover quickly between work bouts is important during elite team handball match-play (Michalsik *et al.*, 2014a). These data provide the first normative values for practitioners to inform selection and highlight physical training requirements for youth females regarding the ability to perform repeated intense running exercise during team handball match-play.

Most research to assess the association between anthropometric and performance characteristics in team handball has focussed on throwing velocity (Wagner *et al.*, 2010; Gorostiaga *et al.*, 2005; van den Tillaar & Ettema, 2004), with little information available on other key determinants of success. Using correlational analysis, this study showed that both stature and body mass were positively related to throwing velocity, and CMJ variables, with benefits of greater stature extending to better maximal and repeated sprinting performance, and better aerobic intermittent performance on the Yo-Yo IR1. Greater gluteal and calf girths were also beneficial for throwing velocity and CMJ power, suggesting that increased muscle mass in these areas contribute to actions involving a strength and power component.

Despite there being no difference between playing standard for body fat, this variable was related to a plethora of performance variables, indicating slower maximal and repeated sprinting times, and reduced Yo-Yo IR1 distance as body fat increased. Throwing velocity and CMJ height were also negatively affected by higher body fat values, indicating the importance of this characteristic to key performance determinants of team handball. The potential for certain anthropometric characteristics to have a positive impact on physical performance promotes the use of normative values from this study when selecting players.

A limitation to this study is that players in the top-elite group were 17.1 years old, compared to 15.7 – 15.8 years old for non-elite and elite players. However, when age was included as a covariate, differences found in anthropometric characteristics between standard were independent of age. These findings suggest that any changes occurring in female anthropometric characteristics between standard in this study are not influenced by age. For performance characteristics, differences between standard were apparent despite age being a significant contributor to most performance characteristics. This significant contribution of age might be a consequence of ~1 year longer training experience in top-elite players in comparison to elite and non-elite players, allowing greater physical development from training practices. Therefore, although the greater age of top-elite players might have contributed to better performance in a variety of tests, results suggest that performance is determined by additional factors independent of player age.

In conclusion, this study indicates a large disparity in anthropometric and physical performance characteristics when top-elite players are compared to both elite and non-elite youth female team handball players. As British non-elite players were found to differ from elite players only in stature, arm girth and throwing velocity, coaches might aid talent identification and development by focussing on these aspects. The present data provide normative values to be used by coaches and re-affirm the importance of a multitude of characteristics for successful youth female competition.

CHAPTER 4:

THE MOVEMENT AND PHYSIOLOGICAL DEMANDS OF ENGLISH YOUTH MALE TEAM HANDBALL MATCH PLAY

4.1 Introduction

Despite the global popularity of team handball with ~19 million players in 795,000 registered teams (International Handball Federation, 2009), research describing the working demands of players during matches is limited. Detailed analysis of demands during match play is an essential requirement for the development of both optimal training practices (Michalsik & Bangsbo, 2002) and match simulations (Dawson *et al.*, 2004). Specifically, greater understanding of such requirements can elucidate the relative contribution and intensity of movement patterns in order to either imitate or overload the physiological systems as part of player preparation (Duthie *et al.*, 2003; Pers *et al.*, 2002; Deutsch *et al.*, 1998).

Of the studies that have investigated the match demands of team handball competition in males, only three have analysed competitive matches in elite adults (Michalsik *et al.*, 2013a, Póvoas *et al.*, 2012, Luig *et al.*, 2008), with others detailing friendly matches in elite adults (Šibila *et al.*, 2004; Pers *et al.*, 2002) and elite youth players (Šibila *et al.*, 2004; Chelly *et al.*, 2011; Souhail *et al.*, 2010). Consequently, there is limited information available that can be deemed representative of true match demands. Moreover, the variations in methodological approaches between these studies, including differences in substitution allowances, playing times, and individual player versus positional monitoring, make interpretation challenging.

Analysis of player movement demands over the course of a match is of primary interest to researchers as it can help to determine the extent to which fatigue is manifested. Increased fatigue could be a limiting factor to account for decrements in match performance, which could be detrimental to the outcome of a competition (Reilly *et al.*, 2008; Rampinini *et al.*, 2007). Indeed, recent data in elite male players suggest the occurrence of fatigue-induced decrements throughout a competitive team handball match are expressed via decreased high-intensity activity and heart rate from the first to the second half (Michalsik *et al.*, 2013a;

Póvoas *et al.*, 2012). In addition, decreases in the number of high-intensity match actions, such as stops, changes of direction and body contact are also observed (Póvoas *et al.*, 2012). Similar results were also reported in elite youth males from the first to second half of friendly matches, with players covering less distance at high speed, alongside decreases in the performance of technical actions and lower average heart rates (Chelly *et al.*, 2011). Assessment of neuromuscular performance during or immediately after matches can also be used to indicate the extent to which fatigue is manifested. Impairment of contractile function can lead to decrements in neuromuscular force and compromise the quality of movement patterns during match activities (Ronglan *et al.*, 2006). Reductions in jump height (5.2%) and rate of force production (~30%), as well as decreased strength and power of the knee extensors and flexors has been reported in youth male players after a team handball simulation protocol (Thorlund *et al.*, 2008). However, this protocol probably overestimated typical match demands owing to a higher relative movement speed (131 $m \cdot min^{-1}$) than has been previously reported for outfield players during competitive matches (53 - 90 $m \cdot min^{-1}$, Michalsik *et al.*, 2013a; Póvoas *et al.*, 2012, Luig *et al.*, 2008), and did not allow for substitutions. As there are currently no studies available assessing responses to matches in male players, it is unclear whether competitive team handball competition impairs neuromuscular performance.

Growth in popularity of team handball in England has occurred in recent years, evidenced by a 96% increase in the number of registered club members, and greater participation in organised school competition between 2012-13 (48% U15 National School Cup; England Handball Association, personal correspondence). With this in mind, it is essential that this new influx of players is offered the most appropriate training environment. At present, no research exists on the match demands experienced by players from England during their domestic competition. A better understanding of the demands imposed on home nation players could play a key role in better preparing players for international matches against more developed team handball nations. Identification of key weaknesses and areas for progression could aid the development of training practices and improve the overall standard of match play at league level in Great Britain (Brewer *et al.*, 2010).

This study aimed to provide analysis of team handball match play in youth English players participating in the U18 Men's National League through the assessment of player movement demands, technical actions and heart rate during match play. Secondly, the impact of team handball competition on fatigue during and after matches was also investigated.

4.2 Methods

4.2.1 Participants

This investigation comprised two parts. Part 1 used video analysis to monitor the movement demands and technical match actions of 22 male team handball outfield players (16.23 ± 0.92 y). Video analysis was conducted for all 24 league matches, with 1 - 2 players being individually recorded during each match (total files = 22). Three players were omitted from analysis either due to injury during matches or very short playing times (< 10 min). Of the remaining players, 11 players were backs, 7 were wingers, and 4 were pivots. There were no restrictions on playing time but coaches were asked to identify one key player to ensure adequate recording for each match could take place.

Part 2 monitored the physiological and neuromuscular responses of team handball match play in 21 male outfield players (age 16.08 ± 0.72 y), which included 13 (59%) of the players who also participated in Part 1. The recruitment of additional players for Part 2 was required due to coach restrictions at half-time/ full-time (i.e. team talks), meaning that players were unable to participate in physical testing and were thus omitted from analysis. Players were tested for physical performance measures (20 m sprint, counter-movement jump (CMJ), throwing velocity) and blood lactate concentration at baseline, half-time and full-time. Heart rate was also monitored continuously during matches.

The U18 Men's National league consisted of seven teams at the time of data collection, with matches lasting for 40 min (2 x 20 min halves with 5 min break between halves). All analysis was conducted for the entire match (e.g. inclusive of all breaks for stoppages in play due to injury, time-outs *etc*.), in order to provide comprehensive analysis of full-match demands as opposed to ball-in-play time only (Póvoas *et al.*, 2012). The league structure requires all teams to play each other once in the preliminary stages, with the best teams progressing to the semi-finals and finals. Players from both studies were taken from five teams (range: 2 - 5 players from each team) competing in the English U18 Men's National League in the 2012 - 13 season from November to March. Goalkeepers were excluded from the study due to the large differences in playing demands. All matches were played at the same venue between 0900 h and 1600 h. The study was approved by the England Handball Association and the Faculty of Applied Sciences Research Ethics Committee. All participants completed written informed consent and a health screening questionnaire before taking part.

4.2.2 Procedures

Part 1

4.2.2.1 Movement characteristics

Individual player movement characteristics were identified from time-motion analysis using tripod mounted (Libec TC-650 DV, HEIWA SEIKI KOGYO CO., LTD, Japan) video cameras (Canon HS200, Canon Inc, Japan). Players were individually tracked, ensuring the player’s whole body was in shot at all times. Player movement patterns were divided into eight locomotor categories, according to the methods of Póvoas *et al.* (2012): (1) standing, (2) walking, (3) jogging, (4) striding, (5) sprinting, (6) backward movement, (7) sideways low-intensity movement, (8) sideways high-intensity movement (for full definitions, see Appendix 7). Locomotor activities were then grouped into high-intensity (4, 5 and 8) and low-intensity activity (1, 2, 3, 6 and 7). For each locomotor category, results were represented as frequency of occurrences (*n*), total time (s), the percentage of total time (%), and the average duration (s). Activities were broken down into 5 min intervals for comparisons based on recommendations from previous literature (Kempton *et al.*, 2013; Póvoas *et al.*, 2012; Mohr *et al.*, 2005).

4.4.2.2 Technical match actions

Technical match actions were selected based on recommendations from previous research (Gruić *et al.*, 2006; Meletakos *et al.*, 2011; Ohnjec *et al.*, 2008; Póvoas *et al.*, 2012) and the head coach of the Great Britain Men’s International handball team. Actions were broken down into shots (total shots, area: 6 m, 7 m, 9 m, and goal success rate by area), body contact (total, total offensive, total defensive, offensive and defensive clasp/ grab and push/ shove actions), and other (technical error in attack, technical error in defence, and total jumps; including all jump shots; see Appendix 7 for full definitions).

4.2.2.3.Reliability

Reliability data were established from three full matches that were randomly selected by the researcher. Using Roberts *et al.* (2006) CV% classification for reliability (i.e. <4.9% good, 5-

9.9% moderate, >10% poor), intra-reliability for the movement demands yielded a moderate intra-reliability score (9.2 CV%). Intra-reliability of the technical actions was assessed using the method of Cooper *et al.* (2007), revealing that all performance indicators scored 100% ±1 level of agreement (Thomson *et al.*, 2012; Cooper *et al.*, 2007; Bloomfield *et al.*, 2005).

Part 2

4.2.2.4 Physical performance testing

Participants were tested at their respective clubs for baseline physical performance ~2 - 6 weeks prior to match monitoring. After completing their standardised club warm-up and familiarisation to the procedures, all participants completed the same tests in the following order: maximal counter-movement jump (CMJ), 20 m sprint with 10 m split, throwing velocity, and the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1). Participants were given 2 - 3 min recovery between conditions, and ~5 min recovery between activities. Baseline (resting) concentrations of blood lactate ([BLa]) and glucose ([Glu]) required players to report to the investigator prior to warm on the match testing day.

Match testing required players to perform CMJ, 20 m sprint and throwing velocity measures at half-time and full-time. Due to time restrictions between halves, only 2 attempts at each test were given, with the best attempt recorded for analysis. Additionally, as participants were required to perform tests within a small time window (5 min), minimal recovery was allowed between attempts or activities. Measures of [BLa] were taken at half-time or immediately after a player rotation off the court, providing data that reflected the preceding work period. Thus, if players were rotated off court <5 min before the end of each half, then results were included in half-time or full-time analysis. For purposes of this study, all physiological measurements were taken during the preliminary stages of the league competition due to the potential inconvenience testing procedures could place on teams in the final stages.

Participants began the CMJ (CV = 2.7%) in an upright position, with the hands placed on the hips. Participants flexed at the knee to a self-selected depth and then jumped for maximal height. Jump height was recorded from flight time using the equation of 9.81 x flight time^2 /8 (Bosco *et al.*, 1983) measured using an infrared timing system (Optojump, Microgate S.r.l., Bolzano, Italy) interfaced with a laptop.

Sprint performance over 20 m (CV = 2.8%) was measured using electronic timing gates (Brower Timing Systems, Microgate, Bolzano, Italy) placed at 0, 10 and 20 m. Players began from a standing start, with their foot behind the 0 m line and began when ready.

Throwing velocity (km·h^{-1}) was assessed using a radar gun (Bushnell Sports Radar Gun, 101911, Kansas City, USA), placed 1 m to the side of the goal post, and perpendicular to the player (CV = 3.3%). Using a size 2 handball (no resin), players completed a maximal effort set shot with three-step run-up from 9 m without a goalkeeper (Vila *et al.*, 2012). Only shots on target were selected for analysis.

Blood lactate (Lactate Pro, Akray, Kyoto, Japan) was taken for each participant, beginning with the finger being cleaned with a medi-wipe to remove any contaminants and dried with a gauze swab. A softclix lancet device was then used to puncture the site, with the first drop of blood wiped away using a gauze swab. After applying light pressure around the site, blood was applied to the lactate (15 µl) strips, which automatically analysed the samples.

4.2.2.5 Heart rate monitoring

Heart rate (HR) for each player was monitored continuously throughout matches (Activio Sport System, Perform Better, BM-CS5EU, China). Individual player exercise periods were analysed for each match, which included all time spent on the court (e.g. inclusive of all breaks for stoppages in play due to injury, time-outs *etc*.), as this provides a complete representation of match demands and contributes to the working demands during competition. Individualised maximal heart rate was derived upon completion of the Yo-Yo IR1 test (as previously described in Chapter 3). This allowed peak and average values to be expressed as both absolute ($b\cdot min^{-1}$) and relative to maximal heart rate (%HRmax). In addition, summated HR was calculated to indicate training load of players, using the following equation (Edwards, 1993):

(Duration in *zone 1* x 1) + (Duration in *zone 2* x 2) + (Duration in *zone 3* x 3) + (Duration in *zone 4* x 4) + (Duration in *zone 5* x 5), where *zone 1* = <60%, *zone 2* = 60-70%, *zone 3* = 70-80%, *zone 4* = 80-90%, and *zone 5* = 90-100% HR_{max}.

4.2.3 Statistical analysis

Assumptions of normal distribution and homogeneity were checked using Kolmogrov Smirnoff and Levene tests. Values for technical match actions were not normally distributed and subsequently non-parametric analysis was performed. Differences between halves were analysed using the Wilcoxon signed-rank test. Differences over time (5 min breakdown) were analysed using Friedman's ANOVA with follow-up *post hoc* Wilcoxon signed-rank tests performed to follow-up any significant effects. Physical performance and heart rate data were normally distributed, and movement characteristics revealed that 62% of cases were normally distributed, thus subsequent parametric analysis was performed for these variables.

Differences between halves were calculated using paired-samples *t*-tests. Differences over time (5 min breakdown) were calculated using a repeated-measures ANOVA, with follow-up post-hoc *t*-tests performed for any significant effects. Effect sizes (ES) were calculated as the difference between the means divided by the pooled standard deviation, with values of 0.2, 0.5, and above 0.8 considered to represent small, medium, and large differences, respectively (Cohen, 1988). Analyses were performed using Predictive Analytics Software (PASW) Statistics v.18 (SPSS Inc., Chicago, IL), with the alpha level set at $P < 0.05$.

4.3 Results

4.3.1 Movement characteristics

Players' total match time was 36:24 ± 4:36 min, spending 94.24 ± 3.6% and 3.93 ± 0.82% of total time in low and high-intensity activity, respectively (Table 4.1).

The total amount of time spent taking part in striding, low-intensity sideways movement and total low-intensity movement was reduced during the second half of matches ($P < 0.05$). However, when values were represented as percentage of total playing time, only low-intensity sideways movement was lower ($P < 0.05$). When movement categories were analysed in 5 min intervals, time spent in total low and high-intensity activities were unchanged over time ($P > 0.05$). For individual movement categories, differences were found in the amount of time spent in low-intensity sideways movement $F(7,91) = 4.447$, $P < 0.001$, with *post-hoc* analysis showing differences between 0 - 5 min (41.52 ± 18.85 s) in comparison to 25 - 30 min (24.59 ± 18.64 s; $P = 0.025$) and 30 - 35 min (21.76 ± 20.13 s; $P = 0.026$). Time spent walking was also different over time $F(7,91) = 2.452$, $P = 0.024$, with *post-hoc* analysis showing increases from the first 5 min to 5 - 10 min (47.31 ± 21.35 s *cf.* 74.22 ± 26.63 s, $P = 0.02$).

Total activity changes (i.e. movement category) for the match were 298 ± 44, with 165 ± 23 in the first half and 133 ± 29 in the second half ($P < 0.001$). This equated to 7.40 ± 0.76 s between activity changes for the total match, with 7.10 ± 0.83 s and 7.76 ± 1.0 s between activities during the first and second half, respectively ($P = 0.007$). When categorised into 5 min intervals, the frequency of activity changes were significantly different over time ($F(7,119)= 4.471$, $P < 0.001$). Activity changes were highest in the first 5 min (44.78 ± 7.50) being significantly different to all other 5 min periods from 20 - 25 min onwards (37.56 ± 11.70 to 32.33 ± 12.77; $P < 0.05$). Activity changes were also higher in 5 - 10 min compared to 25 - 30 min and 30 - 35 min ($P < 0.05$).

Average duration spent in low-intensity movements was 7.77 ± 0.85 s, while players spent 3.93 ± 0.82 s in high-intensity activities. Players spent a shorter average duration in low-intensity activities in the first half compared to the second half (7.38 ± 0.86 s *cf.* 8.02 ± 1.02 s, $P = 0.005$), while there were no differences between halves for average time spent in high-intensity activities (4.26 ± 2.38 s *cf.* 4.07 ± 1.23 s). When broken down into 5 min intervals, results showed that average duration spent in low-intensity activities was shortest in the first 5 min of match-play (6.48 ± 1.10 s) and then significantly increased at min 15 - 20 (7.88 ± 1.34 s), 20 - 25 (8.51 ± 1.54 s), 25 - 30 (8.51 ± 1.54 s), 30 - 35 (8.24 ± 1.75 s) and 35 - 40 (8.55 ± 1.62 s) (all $P < 0.05$), while there were no differences for average duration spent in high-intensity activity $P > 0.05$; see Figure 4.1).

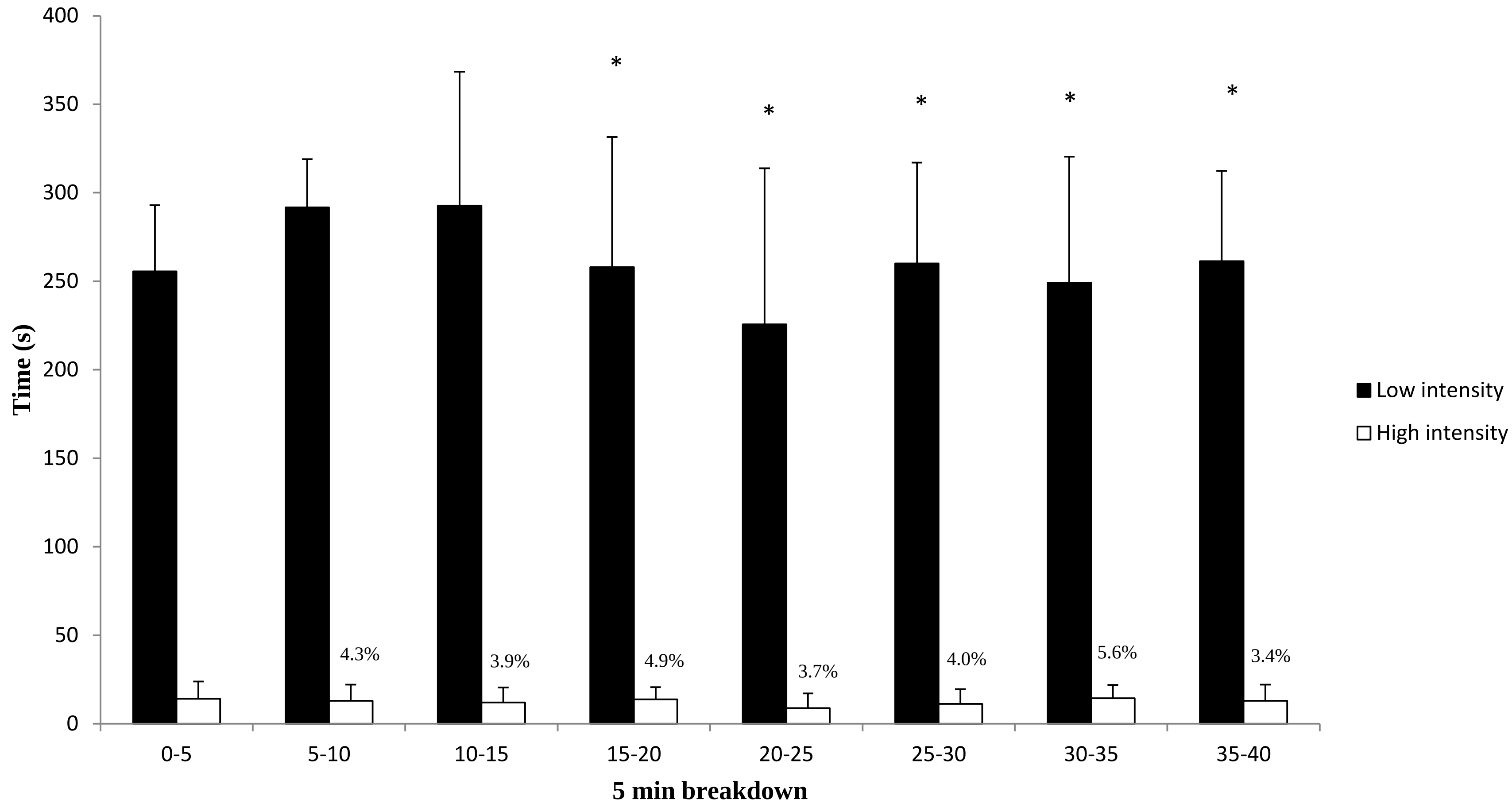


Figure 4.1: Total time spent in low-intensity and high-intensity activity broken down into 5 min intervals.* denotes significant difference in total time spent in low-intensity activity from 0-5 min (P< 0.05).

Table 4.1: Frequency, time and percentage of total time comparisons for movement categories between the first and second half (*n*= 22)

Movement characteristic		**First half**	**Second half**	**Total match**	***P***	**Effect size *(d)***
Total playing time (min)		19:18 ± 2:13	17:06 ± 4:06	36:24 ± 4:36	0.105	
Standing	Frequency (n)	45.91 ± 9.58	37.64 ± 10.45	83.55 ± 16.58		
	Time (s)	434.17 ± 95.80	415.42 ± 131.17	849.59 ± 160.48	0.598	0.16
	% Total time	35.92 ± 8.11	40.38 ± 6.55	38.15 ± 5.64	1.0	
	Average duration (s)	9.59 ± 1.73	11.12 ± 2.45	10.28 ± 1.45	0.024*	
Walking	Frequency (n)	30.64 ± 7.34	27.00 ± 9.95	57.64 ± 15.37		
	Time (s)	261.32 ± 107.88	236.25 ± 112.20	497.57 ± 201.57	0.202	0.32
	% Total time	21.22 ± 7.59	22.76 ± 8.38	21.99 ± 6.84	0.392	
	Average duration (s)	8.37 ± 2.22	8.54 ± 1.87	8.43 ± 1.81	0.711	
Jogging	Frequency (n)	37.55 ± 9.53	31.91 ± 10.89	69.45 ± 18.85		
	Time (s)	207.86 ± 62.54	184.60 ± 69.10	392.45 ± 117.50	0.082	0.35
	% Total time	18.09 ± 4.42	18.43 ± 5.36	18.26 ± 4.29	0.741	

	Average duration (s)	5.51 ± 0.68	5.77 ± 0.68	5.64 ± 0.54	0.167	
Striding	Frequency (n)	4.32 ± 2.98	3.23 ± 3.10	7.55 ± 5.34		
	Time (s)	17.28 ± 14.16	13.56 ± 15.69	30.83 ± 25.07	<0.001*	0.25
	% Total time	2.00 ± 2.17	1.16 ± 1.25	1.58 ± 1.34	0.1	
	Average duration (s)	3.81 ± 1.01	3.47 ± 1.95	3.90 ± 1.08	0.337	
Sprinting	Frequency (n)	1.73 ± 1.91	1.41 ± 1.33	3.14 ± 2.62		
	Time (s)	8.02 ± 16.78	4.96 ± 5.10	12.99 ± 17.58	0.82	0.25
	% Total time	1.32 ± 2.99	0.53 ± 0.59	0.92 ± 1.51	0.243	
	Average duration (s)	3.69 ± 1.96	2.81 ± 1.75	3.73 ± 1.62	0.194	
Backwards movement	Frequency (n)	13.55 ± 6.92	10.64 ± 5.47	24.18 ± 11.01		
	Time (s)	56.23 ± 30.97	50.12 ± 28.83	106.35 ± 52.68	0.324	0.20
	% Total time	5.16 ± 3.32	5.27 ± 2.80	5.22 ± 2.52	0.884	
	Average duration (s)	4.07 ± 0.76	4.66 ± 0.89	4.22 ± 0.72	0.046*	
LI sideways movement	Frequency (n)	22.14 ± 7.85	14.18 ± 6.24	36.32 ± 12.23		
	Time (s)	135.21 ± 74.27	93.60 ± 49.73	233.48 ± 107.22	0.003*	0.66

	% Total time	12.53 ± 5.90	8.77 ± 4.45	10.65 ± 4.60	0.002*	
	Average duration (s)	5.87 ± 1.94	6.43 ± 1.45	6.26 ± 1.13	0.187	
HI sideways movement	Frequency (n)	8.77 ± 3.56	6.91 ± 4.13	15.68 ± 6.71		
	Time (s)	33.62 ± 18.82	27.15 ± 15.81	60.77 ± 29.18	0.123	0.37
	% Total time	3.94 ± 3.43	2.69 ± 1.61	3.32 ± 2.07	0.101	
	Average duration (s)	3.75 ± 0.77	4.03 ± 1.10	3.85 ± 0.68	0.294	
Total low-intensity activity	Frequency (n)	149.77 ± 20.36	118.32 ± 33.00	264.05 ± 54.65		
	Time (s)	1094.78 ± 123.17	952.75 ± 278.99	2025.97 ± 379.05	0.044*	0.66
	% Total time	92.92 ± 6.73	95.63 ± 2.01	94.24 ± 3.60	0.077	
	Average duration (s)	7.38 ± 0.86	8.08 ± 1.03	7.77 ± 0.84	0.005*	
Total high-intensity activity	Frequency (n)	14.82 ± 5.89	11.09 ± 5.90	25.77 ± 9.75		
	Time (s)	58.93 ± 38.68	43.88 ± 23.35	102.31 ± 46.11	0.13	0.47
	% Total time	7.26 ± 7.05	4.37 ± 2.01	5.86 ± 3.71	0.075	
	Average duration (s)	4.26 ± 2.38	4.07 ± 1.22	3.93 ± 0.82	0.734	

4.3.2 Technical match actions

The frequency of all match actions are presented in Table 4.2. Total body contact (*z*= -3.515, $P < 0.001$), offensive body contact (*z*= -2.82, $P = 0.021$) and defensive body contact (*z*= -2.770, $P = 0.004$) all decreased from the first to second half. When broken down into body contact type, there were also reductions between halves for offensive (*z*= -2.193, $P = 0.028$) and defensive (*z*= -2.577, $P = 0.009$) push/ shove actions, respectively. There were no other differences for any other technical match actions.

When broken down into 5 min intervals, total body contact (x^2 (7)= 19.089, $P = 0.008$) and defensive push/ shove actions (x^2 (7)= 14.934, $P = 0.037$) were the only variables displaying significant changes over time. Total body contact was different between 0 - 5 and 25 - 30 min (3.27 ± 2.53 *cf.* 1.36 ± 1.09; *z*= -3.454, $P < 0.001$), and between 10 - 15 and 25 - 30 min (3.05 ± 2.06 *cf.* 1.36 ± 1.09; *z*= -3.094, $P = 0.001$; see Figure 4.2). *Post-hoc* analysis for defensive push/ shove actions revealed no further differences.

Table 4.2: Frequencies of technical match actions (mean ± standard deviation).

Match Actions (frequency)	First half	Second half	Total match
Total Shots	4.09 ± 3.05	3.68 ± 2.68	7.77 ± 4.74
6 m successful	1.32 ± 1.56	1.55 ± 1.18	2.86 ± 2.12
6 m unsuccessful	1.32 ±1.76	0.95 ± 1.13	2.27 ± 2.55
6 m efficiency (%)	51.86 ± 33.47	65.81 ± 29.42	59.12 ± 28.05
7 m successful	0.45 ± 0.86	0.14 ± 0.35	0.59 ± 1.01
7 m unsuccessful	0.09 ± 0.29	0.09 ± 0.29	0.18 ± 0.40
7 m efficiency (%)	90.0 ± 25.82	62.50 ± 47.87	75.56 ± 35.39
9 m successful	0.27 ± 0.63	0.36 ± 0.95	0.64 ± 1.26
9 m unsuccessful	0.64 ± 0.90	0.59 ± 0.91	1.23 ± 1.41
9 m efficiency (%)	24.17 ± 36.10	30.71 ± 42.60	25.0 ± 34.44
Total body contact	11.14 ± 6.10*	6.22 ± 3.79	17.36 ± 8.77
Offensive	5.32 ± 3.76*	3.18 ± 2.26	8.50 ± 4.99
Clasp/grab offense	1.91 ± 2.05	1.50 ± 1.26	3.41 ± 2.87
Push/ shove offense	3.41 ± 2.94*	1.77 ± 1.90	5.18 ± 3.86
Defensive	5.82 ± 5.10*	3.41 ± 2.79	9.23 ± 6.91
Clasp/grab defence	2.41 ± 2.52	2.36 ± 2.84	4.77 ± 4.82
Push/ shove defence	3.41 ± 3.17*	1.50 ± 1.44	4.91 ± 3.52
Other actions			
Technical error in attack	0.86 ± 0.99	1.23 ± 1.41	2.09 ± 1.97
Technical error in defence	0.23 ± 0.75	0.41 ± 0.80	0.64 ± 1.45
Jumps	8.50 ± 5.14	7.36 ± 3.96	15.86 ± 6.28

Note: Values are presented per participant and are not overall team totals. Significance is denoted by * $P < 0.05$.

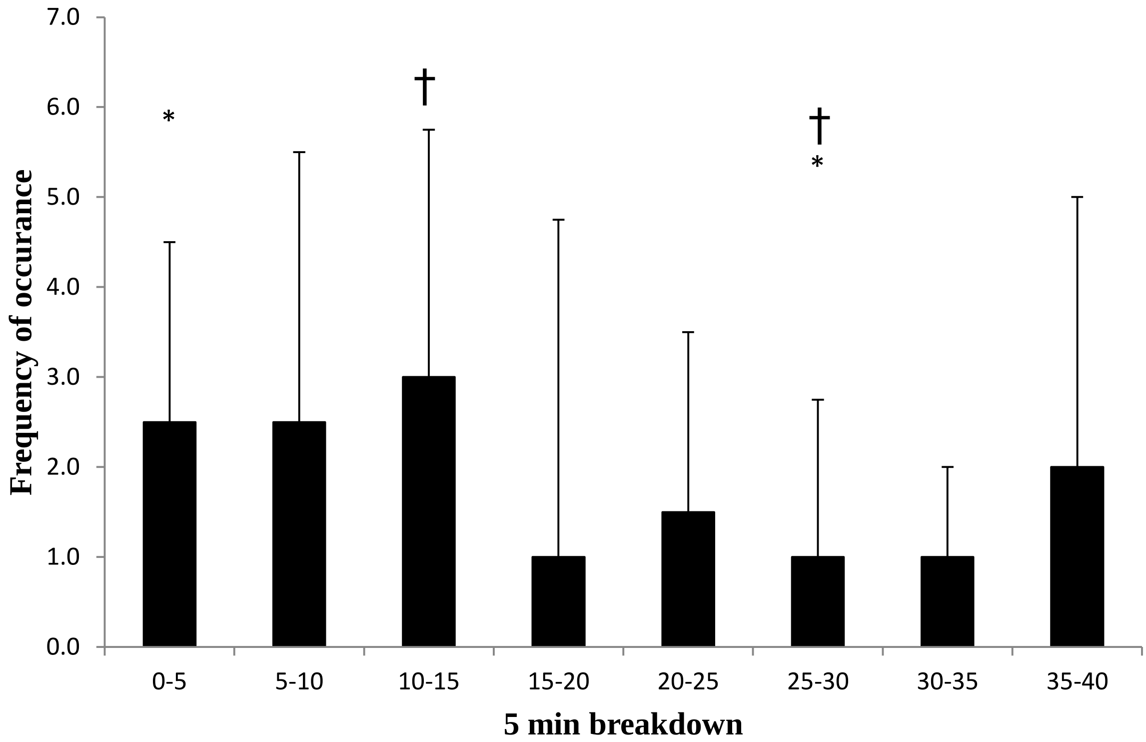


Figure 4.2: Total body contact frequencies (median ± IQR) broken down into 5 min intervals. * designates significant difference from 0 - 5 and 25 - 30 min, and †signifies significant difference between 10-15 and 25 - 30 min (P < 0.05).

4.3.3 Physical performance testing

Average scores for neuromuscular responses and blood lactate testing are presented below (Table 4.3). There were no differences between halves in neuromuscular performance ($P > 0.05$). Blood lactate concentration increased over time $F(2,32) = 6.590$, $P = 0.004$, with *post-hoc* tests revealing large increases from baseline to half time ($P = 0.006$) and from baseline to full time ($P = 0.044$) but differences were trivial between half time and full time ($P = 1.0$).

Table 4.3: Physical performance testing and blood markers at baseline (pre-match), half-time and full time (mean ± SD)

Test	Baseline	Half-time	Full-time	*ES baseline-half time*	*ES baseline-full time*	*ES (half time and full time)*
10 m sprint (s) (*n*= 15)	1.93 ± 0.10	1.89 ± 0.12	1.88 ± 0.14	0.36	0.41	0.08
20 m sprint (s) (*n*= 15)	3.31 ± 0.13	3.29 ± 0.21	3.31 ± 0.27	0.11	0	-0.08
Throwing velocity ($km \cdot h^{-1}$) (*n*= 17)	74.69 ± 6.13	72.05 ± 7.44	71.57 ± 8.10	0.39	0.43	0.06
CMJ (cm) (*n*= 15)	35.33 ± 7.76	35.52 ± 6.82	34.95 ± 7.33	-0.03	0.05	0.09
BLa (*n*= 17)	2.02 ± 1.32	4.09 ± 2.35*	3.81 ± 2.76*	-1.09	-0.83	0.11

Note: *denotes significantly different from baseline ($P < 0.05$). Values are accompanied by effect sizes and qualitative interpretations that are presented directly below in italics. Effect sizes were calculated as the difference between the means divided by the pooled standard deviation, with values of 0.2, 0.5, and above 0.8 considered to represent small, medium, and large differences, respectively (Cohen, 1988). ↑ increase, ↓ decrease.

Table 4.4: Heart rate data for the first and second half of matches (*n*= 16)

Variable	First half	Second half	Full match	*t*	*P*	*Effect size (d)*
Time played (min)	16:51 ± 3:51	14:36 ± 5:37	31:27 ± 7:22	0.141	0.18	0.47
Maximum HR (b·min^{-1})	194 ± 10	193 ± 12	193 ± 11	0.058	0.95	0.09
Average HR (b·min^{-1})	180 ± 12	175 ± 16	178 ± 13	1.812	0.09	0.35
Average HR (%)	89.6 ± 5.4	88.0 ± 6.4	88.3 ± 4.9	1.132	0.28	0.27
Time > 85% HR_{max} (min)	14:29 ± 5:57	10:55 ± 5:59	22:02 ± 10:13	1.991	0.07	0.60
Percentage of total time spent > 85% HR_{max}	80.3 ± 25.1	71.3 ± 29.9	72.7 ± 23.3	1.202	0.25	0.33
Summated HR (AU)	74.8 ± 22.8	60.8 ± 24.5	135.6 ± 36.2	1.722	0.11	0.59

Values are accompanied by effect sizes and qualitative interpretations that are presented directly below in italics. Effect sizes were calculated as the difference between the means divided by the pooled standard deviation, with values of 0.2, 0.5, and above 0.8 considered to represent small, medium, and large differences, respectively (Cohen, 1988). ↑ increase, ↓ decrease.

All heart rate variables are presented in Table 4.4. Players spent the greatest percentage of total time in the most intense category (*zone 5*: 49.79 ± 34.77%), followed by *zone 4* (29.14 ± 22.08%), *zone 3* (8.71 ± 10.49%) *zone 2* (3.64 ± 4.68%) and *zone 1* (0.6 ± 1.40%). Results showed that time spent in *zone 1* (3.50 ± 10.72 s *cf.* 9.71 ± 22.01 s) and *zone 2* (22.64 ± 39.84 s *cf.* 44.79 ± 60.27 s) was greater to a small extent (*ES*= -0.36 to -0.43, $P > 0.05$) in the second half of matches. While times in *zone 3* (74.43 ± 106.71 s *cf.* 95.0 ± 119.89 s) and zone *4* (285.71 ± 246.58 s *cf.* 271.1 ± 253.30 s) were similar between halves (*ES*= -0.18 to 0.06), the time spent in *zone 5* (614.71 ± 423.06 s *cf.* 435.93 ± 325.59 s) approached moderately higher values (*ES* = 0.47) for the first half compared to the second half (all $P > 0.05$, see Figure 4.3).

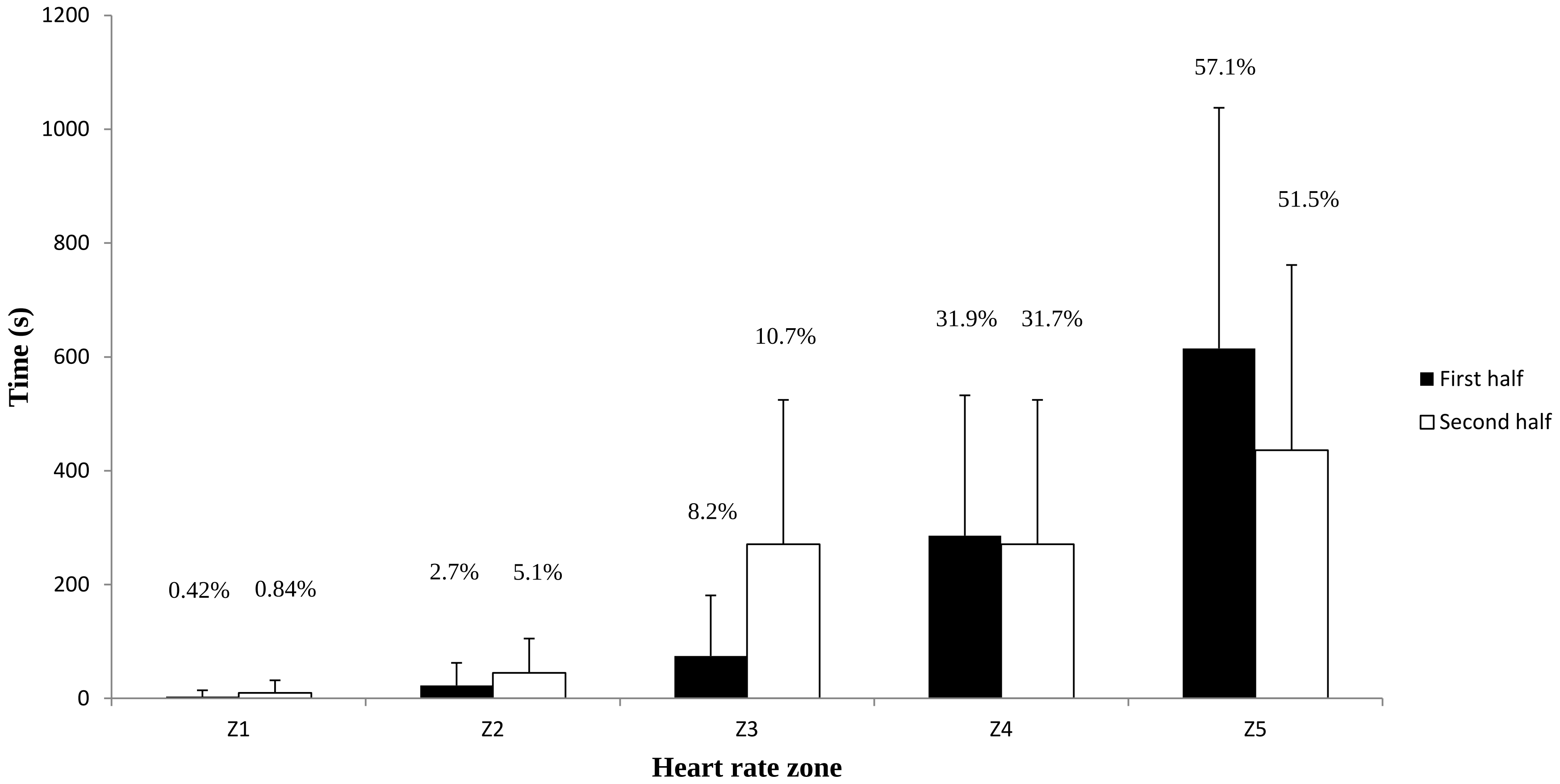


Figure 4.3: Total time (s) spent in each heart rate zone and percentage of total match time. Values are based on individualised maximum heart rate taken from the Yo-Yo IR1 test. Zone 1 = 0 - 60, Zone 2 = 60 - 70, Zone 3 = 70 - 80, Zone 4 = 80 - 90, Zone 5 = 90 - 100 % HR_{max}.

4.4 Discussion

This is the first study to provide a comprehensive analysis of competitive English youth male team handball match play encompassing movement, technical, neuromuscular and heart rate responses. Key findings were that players spent the majority of time in low-intensity movement activities (~94%), although average heart rates of ~88% HR_{max} highlight the large physiological demand imposed by other activities during matches. Players performed less activity changes, spent greater average durations in low-intensity movement, and had a lower frequency of body contacts in the second compared to the first half of matches. Heart rate variables were unchanged between halves, although players spent moderately more time in the highest intensity zone and had moderately higher summated heart rate in the first compared to the second half. While neuromuscular performance (sprints, jumps and throws) was unchanged over the course of a match, there were small increases in blood lactate concentration from baseline but no difference between halves.

Total playing time for Part 1 was ~36 minutes, with players spending the majority of match time in low-intensity movement activities, such that standing and walking accounted for ~60% of overall match time. This is similar to elite friendly matches of youth and adult mixed players (59%, *Š*ibila *et al.*, 2004) but lower than has previously been reported for adult players in both the top Portuguese (78%, Póvoas *et al.*, 2012) and Danish (76%, Michalsik *et al.*, 2013a) leagues. The total time spent taking part in high-intensity activity was ~5.8% with sprinting accounting for <1%. Despite these data representing players who would be considered non-elite (i.e. English Youth League), findings revealed that total time spent in high-intensity activity compared favourably to that reported for elite players (1.7 – 7.7%, Michalsik *et al.*, 2013a; Póvoas *et al.*, 2012;, Souhail *et al.*, 2010; *Š*ibila *et al.*, 2004). However, further analysis revealed that English players achieved this through different means. When observing the frequency and relative time spent in high-intensity activities, English players performed considerably less bouts of high-intensity running for longer durations compared to elite players. For example, players performed an average of just 11 high-intensity runs (excluding high-intensity sideways movement) with an average relative time of 3.8 s (sprinting: 3.73 s, striding: 3.9 s) in this study, whereas elite players generally perform higher frequencies (19 - 53), with much shorter average durations lasting between 1.05 and 2.95 s (Michalsik *et al.*, 2013a; Póvoas *et al.*, 2012; Chelly *et al.*, 2011; Souhail *et al.*, 2010). Therefore, it appears that the similar percentage of total time spent in high-intensity activity is achieved by notable differences in match dynamics between players from elite teams and those taking part in the English youth league. Although differences in playing time, definitions of high-intensity activity, and relative player age might help to explain some differences, it appears that elite players compete in a much more dynamic game involving frequent sprints incorporating rapid accelerations and decelerations. This is supported by English players performing a lower frequency of activity changes (298) with greater time between each change (7.4 s) compared to that reported for elite youth players (350 – 501 changes, with < 5 s between activities, Souhail *et al.*, 2010; Chelly *et al.*, 2011, respectively), and elite adults (825 - 1,482 changes, with 6.5 and 2.18 s reported between activities, Póvoas *et al.*, 2012; Michalsik *et al.*, 2013a, respectively). The frequency of change in categories of motion provides essential information on how often players are required to continuously change speed via accelerations and decelerations. Previous findings report the negative impact of repeated changes of direction, accelerations and decelerations on the neuromuscular system (Hader *et al.*, 2014; Nédélec *et al.*, 2012; Ronglan *et al.*, 2006). Thus, the lower frequencies of both high-intensity activity and movement category alteration suggest reduced eccentric loading on the neuromuscular system in non-elite when compared to elite players.

Improvement of these movement dynamics might increase the speed of match play, leading to greater physical demands that more closely replicate that experienced during elite competition. Furthermore, findings from rugby league report that starters have faster change of direction speed and acceleration velocity than non-starters (Gabbett *et al.*, 2009), suggesting that the ability to alter movement speed is indicative of higher standard performance. Considering the potential implications on match play, there is a need for English coaches to employ practices that improve the ability of players to perform high-intensity running bouts with frequent changes in speed. For example, recent research has reported a strong correlation (r= 0.96) between squat strength and the number of high-intensity effort bouts performed during match performance in rugby league (Gabbett *et al.*, 2013). Moreover, better performance in a repeated sprint test (Rampinini *et al.*, 2007) and Yo-Yo test (Castagna *et al.*, 2009; Krustrup *et al.*, 2005) was associated with increased high-intensity activity during soccer matches. The observed relationship between physical qualities and physical performance during matches highlights that performance in team handball competition might benefit from including training practices that increase lower body strength, and enhance repeated high-intensity running capacity.

This study also aimed to provide information on key technical actions as determined by team handball literature (Póvoas *et al.*, 2012; Gruić *et al.*, 2006). English players were consistent with elite team handball research in the number of shots taken (7 *cf.* 5 – 10; European Handball Federation, 2012; Michalsik *et al.*, 2011a; Póvoas *et al.*, 2012; Chelly *et al.*, 2011), with greatest goal frequency occurring from 6 m. Previous research from World Championships and Olympic Games has shown that although the greatest shot efficiency is achieved from 6 m (Spate, 2005), a higher percentage of goals are scored from 9 m shots (Meletakos *et al.*, 2011). Therefore, as English players scored a relative match average of just

1 shot from 9 m, with an efficiency of 25%, greater training focus on this important component of play is needed.

Of the other technical match actions, frequency of jumping actions were similar to elite adults (~14, Póvoas *et al.*, 2012) but substantially less than reported in elite youth players (35 - 89, Chelly *et al.*, 2011; Souhail *et al.*, 2010). Reasons for such large disparity with the latter two studies are unclear but may relate to different technical movement definitions between studies. As such definitions were not provided, it is unclear whether jumps were recorded with/ without the ball, or whether jump shots were included.

Players were subjected to ~16 instances of body contact throughout the match, reaffirming that this aspect could contribute considerably to the overall physiological loading of players (Karcher & Buchheit, 2014). Body contact is essential to many aspects of team handball play, with actions in this study being equally prominent in both offensive and defensive phases of play, which could be important when trying to gain a favourable position for shooting, or when blocking the progression of an opponent (Karcher & Buchheit, 2014). Although body contact data in youth male players is scarce, results from this study are comparable to the adult top Portuguese league (16 *cf.* 20, Póvoas *et al.*, 2012), with the slightly higher number of contacts likely due to longer playing times in adult players. However, much greater frequencies of body contact have previously been reported in Danish elite adult players (~71), perhaps suggesting increased physicality required for success in this league. Bearing in mind that Denmark have either won or placed second in recent World and European Championships while Portugal have failed to qualify, the greater physical style of play evidenced by Danish players probably represents requirements at the top standard of competition. Thus, lower standard players might benefit from incorporating a greater number of physical collisions in one-on-one situations during training practices. As the effective production of maximal force and power against an opponent can be instrumental in determining the outcome of a collision (Granados *et al.*, 2008; Gorostiaga *et al.*, 2005), ensuring that players adopt sufficient strength and power training is essential to maximise successful outcomes during collisions.

English players spent less overall time in striding movement, low-intensity sideways movement, and total low-intensity movement in second half of matches compared to the first. This might be explained in part by the lower overall playing time in the second half (~2 min), which although was not significantly higher, might have reduced the overall time spent in a variety of movements. Interestingly, English players were able to maintain high-intensity running during matches, with no difference between the first and second half. These findings are in contrast to other known studies assessing changes in movement demands during elite team handball competition, who all report decreases in high-intensity activities between the first and second half of matches (Michalsik *et al.*, 2013a; P*ó*voas *et al.*, 2012, Chelly *et al.*, 2011). Methodological issues make comparison between studies difficult; namely the analysis of positions rather than individual players (P*ó*voas *et al.*, 2012), and that substitutions were not allowed during matches (Chelly *et al.*, 2011). Although these studies contribute to our understanding of movement demands, such restrictions do not enable the assessment of fatigue-induced decrements over the course of a competitive team handball match. In the only other study to address players under normal match conditions, Michalsik *et al.* (2013a) reported a ~16% reduction in the amount of high-intensity running (fast running and sprinting) between halves, compared to 1.6% (striding and sprinting) in this study. Such a discrepancy is likely explained by the elite adult players from the top Danish league performing 42 more high-intensity runs (53 *cf.* 11) with a considerably greater frequency of activity changes (1,482 *cf.* 298), and longer average playing time (~54 *cf.* ~36 min) than the English youth players. Accordingly, a lower incidence of high-intensity actions during a match coupled with less developed high-intensity capability in English youth players means they do not experience the fatigue (i.e. reduction in high-intensity running) typically reported in adult team players.

Analysis revealed a reduction in activity changes throughout the course of matches, with differences between halves primarily due to higher frequencies of these actions taking place in the first 10 minutes of match play. Likewise, shortest average durations spent in low-intensity activities also occurred in the first 5 minutes of matches. As changes for both variables occurred after the opening stages of match play and did not fluctuate thereafter, it might be suggested that these differences are the result of an alteration of work rate by players in an attempt to preserve high-intensity activity throughout the match (Gabbett *et al.*, 2013). However, whether players consciously adopt such a pacing strategy remains uncertain.

Body contact was the only technical action to change over the course of matches, declining by ~39% from the first to the second half. These reductions are of greater magnitude than observed previously in both elite adult and youth players (~10%, Póvoas *et al.*, 2012; Chelly *et al.*, 2011), suggesting that English players were less able to deal with the high physiological demand imposed by these movements. Previous research suggests that physical contact imposes high eccentric loading on players, contributing to the total amount of high-intensity work (Póvoas *et al.*, 2012). Although tactical changes throughout the course of the match could have caused subtle changes in the frequency of body contact, the relatively large magnitude of this decrease suggests that players experienced transient fatigue when performing this movement, being manifested in the later stages of match play. The large frequency of contacts reported in elite top league matches makes them an essential component to team handball success (Michalsik *et al.*, 2011a). Therefore, both the ability to tolerate these situations over the course of a match, while maintaining effectiveness to beat the opposition player could prove highly advantageous. Players in this study could benefit from being exposed to a large number of contacts in training as is currently proposed in other collision-related team sports (Gabbett *et al.*, 2010). Increased practice of collisions with appropriate technical coaching has previously been suggested in order to increase proficiency and adequately prepare players for the physiological, technical and perceptual demands required (Gabbett *et al.*, 2009).

The heart rate responses of players during competition can provide key information on physiological demands and the intensity of exercise (Achten & Jeukendrup, 2003). In this study, maximum heart rate was 193 $b \cdot min^{-1}$ and average heart rate corresponded to 88% HR_{max}. Average heart rate was slightly higher than has previously been observed in elite team handball (82 - 87%, Póvoas *et al.*, 2012; Chelly *et al.*, 2011; Souhail *et al.*, 2010). Moreover, players in this study spent ~79% of total match time at intensities of >80% HR_{max}, which is greater than reported for elite adult players (53%, Póvoas *et al.*, 2012) and elite youth players (10% [>85% HR_{max}]), while <1% of total match time was spent at intensities lower than 60% HR_{max}. As well as reiterating the findings of previous studies to suggest that the demands of team handball competition place players under high physiological strain (Póvoas *et al.*, 2012), our findings also highlight the apparent greater demand imposed on English team handball players compared to elite players. Thus, although external movement intensity demands were similar with regard to the proportions of time spent in high and low-intensity activity, it appears that English players were subjected to higher internal loads on the cardiovascular system.

Although heart rate analysis did not reveal any significant differences over the course of the match, small effect sizes were found for average heart rate, which was 5 $b \cdot min^{-1}$ lower in the second half compared to the first half of matches (*ES*= 0.35). This was also accompanied by moderate effect sizes showing that players spent less time >85% HR_{max} (*ES* = 0.60) with lower summated heart rate (*ES*= 0.59) in the second half of matches. As the proportion of high-intensity running did not differ between halves, the small to moderate decreases in these variables can be mostly attributed to a reduction in high-intensity technical actions involved in team handball play, as previously proposed by Póvoas and colleagues (2012). The observed decrease in body contact supports this notion, suggesting that these actions contribute to the anaerobic demand of match play leading to greater elevated heart rates when they are more prominent. In the two other known studies assessing heart rate responses to match play, a greater magnitude of change was observed between halves, reporting significantly lower average heart rates, and a decreased amount of time spent in the most intense categories in the second half (Póvoas *et al.*, 2012; Chelly *et al.*, 2011). However, both of these studies reported decreases in the amount of high-intensity running performed in the second half, suggesting that an elevated heart rate response is likely to be indicative of both running and performing technical actions at high-intensity.

Blood lactate concentration remained unchanged from half-time to full-time, indicating that players maintained a stable energy contribution from anaerobic sources in the 5 minutes preceding measurement in both halves. Although it is acknowledged that blood lactate does not reflect muscle lactate (Krustrup *et al.*, 2005), gaining such information aids to our current limited understanding of the anaerobic glycolytic requirements of team handball competition (Karcher & Bucchheit, 2014). At present, changes in the response of lactate to match performance in team handball is confounding with one study in elite youth handball players reporting decreases between halves (Chelly *et al.*, 2011), while blood lactate concentration remained unchanged between halves in elite adults (Michalsik *et al.*, 2014a). Thus, further research is required in order to improve our understanding of the metabolic demand of team handball.

Neuromuscular performance was unchanged at both half-time and full-time, thus suggesting that the working demands of matches did not compromise contractile function of movement patterns involved in sprinting, jumping or throwing. The only other study to investigate neuromuscular responses after competitive team handball matches was in elite female players, reporting no difference in 20 m sprint performance after an international match (Ronglan *et al.*, 2006), however no other neuromuscular measures were recorded. This differs to results from other intermittent sports, including rugby (Twist & Sykes, 2011; McLellan *et al.*, 2010), futsal (Tessitore *et al.*, 2008), and soccer (Rampinini *et al.*, 2011; Krustrup *et al.*, 2010), who all report deterioration of neuromuscular performance after matches. As results from this study suggest that players were exposed to lower high-intensity demand than elite players (i.e. lower number of high-intensity running bouts, change of movement activity and body contact), it is possible that neuromuscular fatigue would have been limited. Repeated high-intensity efforts have previously been associated with fatigue and impairment of neuromuscular function (Perrey *et al.*, 2010). Moreover, additional research suggests more pronounced reductions in muscle activity for the knee flexor muscles following increased change of direction during high-intensity running (Hader *et al.*, 2014). Collectively, these results suggest that the loads imposed on English players did not induce a negative impact on the neuromuscular system, thus allowing players to maintain performance of sprinting, jumping and throwing throughout matches. It must also be noted that shorter playing times of English youth team handball competition (2 x 20 min) might subject players to reduced demands, enabling them to maintain force and power during these primary muscular movements.

A limitation of this study compared to others (e.g. Michalsik *et al.*, 2013a; Luig *et al.*, 2008; *Š*ibila *et al.*, 2004) is the lack of positional analysis of the working demands of team handball competition. This was evidenced in part by the large inter-individual differences between players in movement, technical and physiological variables. However, the disproportionate number of players in each position meant that such analysis was not possible. A greater sample size, with an even distribution of positions would have enabled more detailed analysis, from which training practices can be developed with greater specificity. This notwithstanding, the study is the first to offer comprehensive insight into the match demands imposed on English youth players.

In conclusion, this study highlights the movement and physiological demands of male English youth league team handball players. English players exhibit similar proportions of match time in high-intensity activity to elite players. However, English players achieve this in a different manner to their elite counterparts, which suggests a less dynamic and slower English game. In addition, elevated heart rate during matches alongside less frequent changes of activity and lower instances of high-intensity running compared to elite players possibly reflects the relatively lower physical capacity of English players to deal with the demands of competition. There was some evidence to suggest that players also experienced transient fatigue throughout matches, manifested by the inability of players to sustain the frequency of body contact, and a tendency for reduced heart rate intensity. Collectively these results suggest that English players might benefit from undertaking training practices that induce similar movement patterns to mimic the physiological stress during team handball competition. In particular, findings suggest that practices to improve high-intensity running capacity, alongside lower body strength training should be incorporated into programmes by English coaches. Moreover, a greater focus on body contact in one-on-one situations during training seems key to maximising success, potentially leading to advances in the English game.

CHAPTER 5:

NEUROMUSCULAR AND WELL-BEING RESPONSES OF ENGLISH YOUTH MALE TEAM HANDBALL PLAYERS DURING A THREE-DAY TRAINING CAMP AND INTERNATIONAL TOURNAMENT

The contents of this chapter have previously been presented / published in the following:

Moss, S. L., McWhannell, N., & Twist, C. (2012). Neuromuscular and perceptual fatigue in English male team handball players during international competition. 17th Annual Conference of the European Conference of Sports Sciences, Bruges, Belgium, 4th-7th July.

Moss, S.L., & Twist, C. (2011). Neuromuscular and well-being responses of high-level male handball players during a training camp. British Association of Sport and Exercise Sciences Annual Conference, University of Essex, 6th-8th September.

5.1 Introduction

Team handball is an intermittent contact sport characterized by repeated accelerations, sprints, changes in direction and jumps (refer to Chapter 4; Póvoas *et al.*, 2012; Ronglan *et al.*, 2006). High-intensity cyclic movements (fast running and sprinting) and acyclic movements (feinting, shooting, jumping, body contact) are interspersed with less intense recovery periods consisting of standing, walking or jogging (Šibila, *et al.*, 2004). Analyses of ten matches from the top male Portuguese league revealed that the average total distance covered for outfield players was 4,370 ± 702 m, spending 43% of total match time standing, 35% walking, 8.8% jogging, 2.2% fast running, 0.4% sprinting, 6.3% in sideways movements, and 4.5% backwards running (Póvoas *et al.*, 2012). The intermittent nature of matches requires players to exert force in both cyclic and acyclic movements, placing strain or loading on the skeletal muscles, which leads to increased fatigue and associated performance decrements in endurance, rapid movement and strength (Montgomery *et al.*, 2008; Thorlund *et al.*, 2008).

The impact of match-play on neuromuscular performance has been investigated after a single match in several team sports (refer to Chapter 4), including rugby league (Twist & Sykes, 2011; Twist *et al.*, 2011; McLean *et al.*, 2010), futsal (Tessitore *et al.*, 2008), and soccer (Andersson *et al.*, 2008; Thorlund *et al*, 2009). Scheduling demands during team handball competitions are intense, often requiring players to compete in six to eight, or an even greater number of matches in ten or fourteen days (e.g. World Championships; Gruić *et al.*, 2006). Ronglan *et al.* (2006) reported significant decreases in 20 m sprint (4%) and CMJ (7%) performance of national female team handball players who competed in three matches over the course of three days. Likewise, similar reductions were also apparent when players were monitored over a five-day training camp (Ronglan *et al.*, 2006). Collectively, these findings suggest that neuromuscular function might be compromised in team handball players during periods of intensified competition or training.

An increased training load causes mood disturbances in a dose-dependent relationship, but returns to normal when training load is reduced (Coutts *et al.*, 2007; Halson *et al.*, 2002). In-season player monitoring in rugby league has shown significant correlations between elevated anxiety and increased training load (Elloumi *et al.*, 2008), as well as longer periods of reduced well-being and elevated perceptions of muscle soreness when daily training load was higher (McLean *et al.*, 2010). Similar monitoring in team handball has demonstrated increased social stress alongside increased training load (Bresciani *et al.*, 2010). Detrimental psychological responses are also reported with increased training loads over short periods of time (Hadala *et al.*, 2010; Halson *et al.*, 2002; O'Connor *et al.*, 1991). Mood disturbances of single-day competitions have been reported by Hadala *et al.* (2010) showing elevations in anger and confusion of sailors, performing high-intensity work during a competition, when compared to those performing work at low intensities. O'Connor *et al.* (1991) also found increases in mood disturbance of swimmers after three days of intensified training, alongside rises in muscle soreness, increased rating of perceived exertion (RPE), increased sensations of fatigue, and decreased performance. Similar reductions in mood and performance identified endurance cyclists as overreached after one week of intense training, thus highlighting the negative impact on both physiological and psychological parameters within a short time period (Halson *et al.*, 2002).

Team handball in England is a relatively new and developing sport (England Handball Progress Report, 2010). Indeed, at the time of this study, players from England had not previously been exposed to international competition. The European Championships would offer an intense match schedule for the players with limited recovery, making it important to monitor the physiological and perceptual impact on players in preparation for, and during the tournament. Due to the developing status of team handball in England, there has been no research to assess the responses of any England team handball age group in relation to training or competition. Despite studies exploring the responses of elite adult team handball players to intensified competition (Ronglan *et al.*, 2006), how non-elite players respond to such events is unknown. Such information could prove valuable to coaches managing players during competition (i.e. formulating of effective interchange and player selection strategies), and contribute to the development of appropriate recovery strategies and training recommendations for inexperienced players being exposed to intensified competition for the first time. Such a study will also enable practitioners to examine athlete responses to common scenarios and how effectively training camps replicate the demands of tournaments. Accordingly, the purpose of this study was to investigate the neuromuscular and well-being responses of English male team handball players, who were largely unaccustomed to intensified competition, during (a) a three-day training camp, with particular focus on responses when playing two matches over the course of two days, and (b) a five-day international tournament, assessing responses over five consecutive match days.

5.2 Methods

5.2.1 Participants

Nine male youth team handball players (age: 16.6 ± 0.5 y, stature: 181.3 ± 7.8 cm, body mass: 78.8 ± 12.9 kg; Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) score: 1671 ± 413 m) from the England Handball Association (EHA) talent programme attended the training camp. Eight players were current members of the England under 19s squad, comprising 4 backs, 1 wing, 1 pivot, and 3 goalkeepers.

The international tournament included fifteen English male youth handball players (age 17.1 ± 0.73 y, Yo-Yo IR1 test score 1812 ± 298 m), comprising 6 backs, 4 wings, 2 pivots, and 3 goalkeepers. Apart from one back player who was excluded from analysis due to an injury on day one, all other players were in good health and free from injury. Despite the different physiological demands of goalkeepers and outfield players, the study sought to assess the impact of training and competition in all team members, all of whom would have to cope with physiological and psychological demands. The study was approved by the England Handball Association, and the European Handball Federation. All players provided written informed consent for their participation, and the study was approved by the University of Chester, Faculty of Applied Health Sciences Research Ethics Committee.

5.2.2 Training camp

The training camp was held in April 2011, in preparation for the under 19 European Open Championships taking place in July 2011. The three-day camp consisted of two 90-minute training sessions, two friendly matches against local teams and one training match, which combined mixed Danish and English male teams. Training sessions included moderate to high-intensity work, comprising intermittent technical and tactical drills. Content and intensity of training sessions was decided by the coaches.

The study design required players to complete the same procedures on days one and two, which examined CMJ (before and after match), sprints (before match), well-being (each morning), and heart rate responses (during match). Players also provided sRPE 30 min after each match. Sprint performance was only taken prior to matches due to external constraints. On the day of the training match (day three), players replicated only pre-match measures due to the more relaxed nature and reduced demands that this match would place on team members. Baseline measurements of neuromuscular performance and well-being were taken prior to match one (day one). A schematic of the study design is shown in Figure 5.1(a).

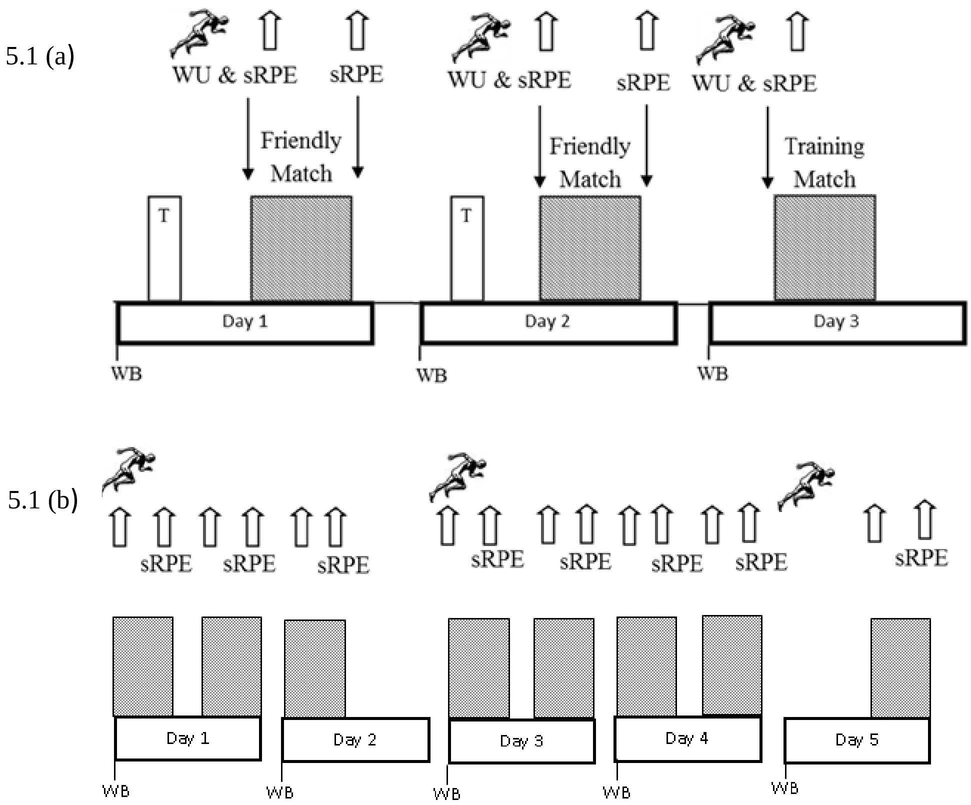


Figure 5.1 (a): Training camp order of procedures, **(b):** Tournament order of procedures. WU & sRPE denotes standardized warm-up and session rating of perceived exertion, WB denotes well-being questionnaire. 10 m sprint, counter-movement jump, and T denotes training session.

5.2.3 International tournament

The European Open Championships were held in Gothenburg, Sweden during July 2011. The tournament consisted of a preliminary round and a final round. Preliminary matches were played on days one, two and three with one half-day break (Figure 5(b)). Each team was randomly assigned to one of four groups consisting of six teams, with each team competing against all others in the group. Final round matches were played on days four and five with one half-day break. This was divided into three sets of placement matches, including a ‘Main round’ (teams placing first and second of each group), an ‘Intermediate round’ (teams placing third and fourth of each group), and a ‘Challenge round’ (teams placing fifth and sixth of each group). England placed sixth and therefore entered the ‘Challenge round’.

The study design required players to undergo neuromuscular testing, which was assessed by monitoring flight time during a CMJ, taken pre- and post-matches, and sprint performance, which was taken three times over the course of the tournament (day one, three, and five) due to external constraints. Perceptual data included a well-being questionnaire, which was completed each morning, and sRPE, taken within 30 min after each match.

5.2.4 Procedures

Prior to all matches, players completed a standardized warm-up dictated by the head coach, consisting of a joint warm-up (5 min), global warm-up (5 min), passing drills (5 min), and shooting exercises (5 min).

5.2.4.1 Neuromuscular performance

Counter-movement jumps began with the participant in an upright position, with the hands placed on the hips. Participants flexed at the knee to a depth self-selected by the individual and then jumped for maximal jump height. Flight time was recorded using an infrared timing system (Optojump, Microgate S.r.l., Bolzano, Italy) interfaced with a laptop. Participants performed two jumps with the longest flight time recorded for analysis. All players were accustomed to the jump procedures as part of their regular monitoring process. Flight time was selected based on the recommendations of Cormack *et al.* (2008) as it provided the most reliable performance measure. Reliability data for this measurement showed coefficient variation of 2.11%. Sprint performance over 10 m was measured using electronic photo cell gates (Brower Timing Systems, Microgate, Bolzano, Italy) placed at 0 and 10 m in an indoor sports hall. Players were instructed to begin from a stationary standing start, with their foot behind the 0 m line. Each player completed two sprints with 2-3 min recovery between each sprint. The best time was recorded for analysis. Reliability data for this showed CV of 3.30%.

5.2.4.2 Player well-being

Player well-being (WB) was assessed each morning using a questionnaire (McLean *et al.*, 2010) comprising five subscales of fatigue, sleep quality, general muscle soreness, stress, and mood rated on a 5-point Likert scale. Higher values were indicative of a positive response to the question, with lower values representing a negative outcome. The total of all scores was used to represent overall well-being for each individual. Similar scales have been shown to have good reliability and validity (i.e. Cronbach alpha coefficients= 0.72 to 0.96; convergent validity determined by correlation, corrected for item overlap = 0.43 to -0.81; De Vries *et al.*, 2003).

5.2.4.3 Heart rate and perceived exertion responses during matches

Each player was fitted with a heart rate (HR; Activio Sport System, Perform Better, BM-CS5EU, China) monitor prior to the match, which was recorded continuously throughout matches. This allowed real-time live streaming of HR via radio frequencies when interfaced with a laptop. Individual player exercise periods were analysed for each match, which excluded time spent off the court, injury time and time-outs. Maximal heart rate was derived from a Yo-Yo test conducted two weeks prior to attending the camp and was used to calculate: time spent above 85%, maximal HR, average HR (%), average HR (b·min^{-1}), and time spent in one of five heart rate zones [(1)10-60, (2) 60-70, (3) 70-80, (4) 80-90, (5) 90-100 %]. Summated HR was then calculated using the following equation (Edwards, 1993):

(*Duration in zone* 1 x 1) + (*Duration in zone* 2 x 2) + (*Duration in zone* 3 x 3) + (*Duration in zone* 4 x 4) + (*Duration in zone* 5 x 5).

Session rating of perceived exertion (sRPE) was taken 30 min after matches using the 0-10 scale as described by Foster *et al.* (2001). The sRPE was calculated after each match by multiplying the individual player's post-exercise score by the duration of time they spent on the court in minutes. Total match duration was calculated for each individual for this purpose by recording the time players entered the game during match play and when they were substituted. Breaks in play for injuries and time outs were not included in the analysis. The sRPE is a modification of the category ratio (CR) RPE scale (Borg *et al.*, 1987), and has demonstrated good reliability in a number of exercise modes and across a range of exercise intensities (Herman *et al.*, 2006; Day *et al.*, 2004). In each instance, participants were showed the scale and were verbally prompted with "How physically exerting was that exercise?" Players were familiar with the measure, having used it regularly to monitor load during training.

5.2.5 Statistical Analysis

Assumptions of sphericity were assessed using Mauchly's test of sphericity ($P < 0.05$), with any violations adjusted by use of the Greenhouse-Geisser correction. Seperate one way analyses of variance (ANOVA) with repeated measures were used to examine for any differences between match data variables, including total playing time, HR, and sRPE, as well as differences over time in 10 m sprint, CMJ and WB when compared to baseline. Paired *t*-tests were performed with a Bonferroni adjustment to follow up any significant effects. The relationship between variables (i.e. neuromuscular performance with markers of fatigue, and well-being measures) were conducted using the Pearson product–moment correlation (*r*) and the coefficient of determination (R^2) for the correlation coefficients. Where appropriate, standard error of the estimate was also presented to establish how the spread of data influenced the correlation coefficient. Effect sizes and magnitude-based inferences (Batterham & Hopkins, 2006), were also calculated where appropriate. Based on the 90% confidence limits, threshold probabilities for a substantial effect were: <0.5% most unlikely, 0.5 – 5% very unlikely, 5 – 25% unlikely, 25 – 75% possibly, 75 – 95% likely, 95 – 99.5% very likely, >99.5% most likely. The threshold for the smallest important change was determined as the within-participant standard deviation x 0.2, with 0.2 - 0.6 being small, 0.6 – 1.2 being moderate, 1.2 being large and >2.0 representing very large effects, respectively. Effects with confidence limits across a likely small positive or negative change were deemed unclear (Hopkins *et al.*, 2006). A predesigned spreadsheet (Hopkins, 2006) was used for all calculations. Analyses were performed using Predictive Analytics Software (PASW) Statistics v.18 (SPSS Inc., Chicago, IL), with the alpha level set at $P < 0.05$.

5.3 Results

5.3.1Training camp

Total match time was 56:06 ± 13:13 min, which accounted for an overall sRPE of 383.2 ± 200.2 arbitrary units (AU) and total average HR of 167 ± 22 b·min^{-1} (*n*= 7). When individual matches were considered, there were no differences in mean playing times (P = 0.49; *ES*=

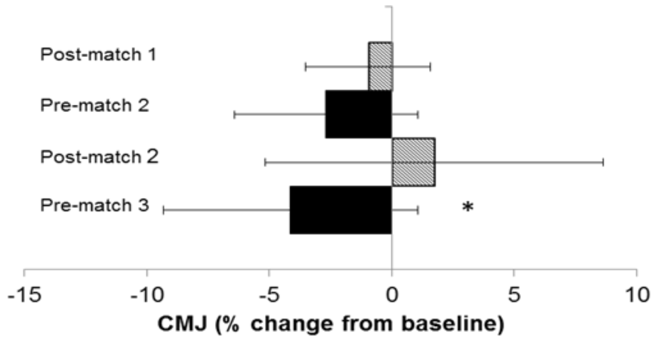
0.39), sRPE (*P* = 0.8; *ES*= -0.07), average HR (*P* = 0.17; *ES* = 0.4) and average percentage of maximal HR (*P* = 0.17; *ES*= 0.45) (Table 5.1).

Table 5.1: Mean playing time, session rating of perceived exertion, average heart rate and average percentage of maximal heart rate for match 1 and match 2 of training camp

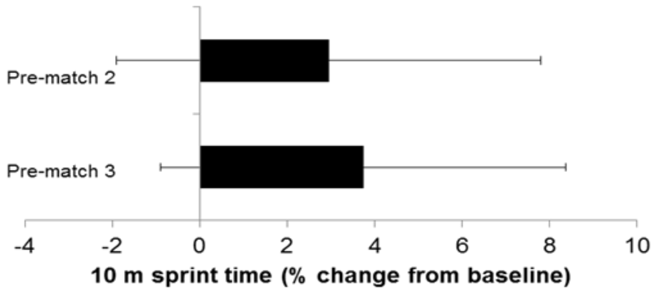
	Playing time (min)	**Session RPE (AU)**	**Average HR ($b \cdot min^{-1}$)**	**Average HR (% HR_{max})**	**Summated HR (AU)**
Match 1	31:06 ± 8:36	188.4 ± 106.7	171 ± 19	85.9 ± 9	126.04 ± 38.6
Match 2	28:00 ± 8:46	194.9 ± 104.0	163 ± 24	81.6 ± 11.4	107.17 ± 48.55

Flight times during CMJ (Figure 5.2 (a)) were 0.54 ± 0.03 s, 0.54 ± 0.04 s, 0.53 ± 0.03 s, 0.55 ± 0.04 s, 0.51 ± 0.03 s, at each of the described time points, respectively. However, only flight time at pre-match three was significantly lower than pre-match one values *(P* = 0.008). There was also an increase between pre-post match two (*P* = 0.008) and between pre match three and post-match two (*P* = 0.002). Sprint performance (Figure 5.2 (b)) showed a tendency to deteriorate during the training camp, with values of 1.89 ± 0.1 s, 1.95 ± 0.11 s and 1.96 ± 0.09 s before matches on day one, two and three, respectively, but values were not significant (*P* = 0.089). Well-being decreased from baseline (18.8 ± 2.26) at day two (17.3 ± 3.5), and day three (16.56 ± 3.4, *P* = 0.07; Figure 5.2 (c)). Furthermore, significant correlations ($P < 0.05$) were observed between well-being scores and 10 m sprint time (*r*= -0.42), and between well-being and pre-match CMJ (*r*= 0.61), and post-match CMJ performance (*r*= 0.51). Muscle soreness was also significantly correlated to 10 m sprint time (*r*= -0.41).

5.2 (a)



5.2 (b)



5.2 (c)

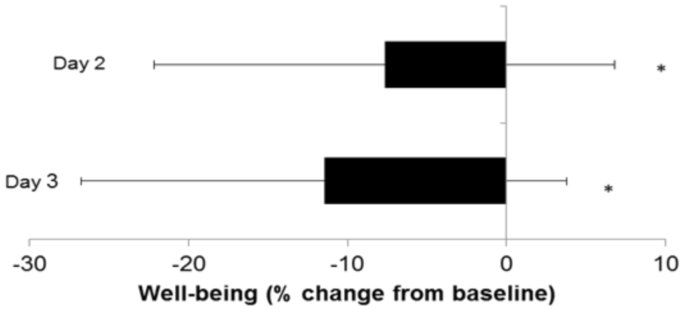


Figure 5.2 (a): Percentage changes in CMJ flight time, **(b):** 10 m sprint performance, and **(c):** well-being responses over three consecutive days. * Significantly different from pre-match 1 ($P < 0.05$).

5.3.2 International tournament

Average warm-up times taken from three tournament matches were 28:43 ± 0:14 min, with values of 160.1 ± 4.59 b·min^{-1}, 128.3 ± 8.2 b·min^{-1}, and 65.4 ± 4.1% for maximal HR, average HR and % HR max respectively (n= 7).

Table 5.2: Mean changes from baseline of selected variables during a training camp

	Day 1	Day 2		Day 3
	Post-match	**Pre-match**	**Post-match**	**Pre-match**
CMJ flight time (s)	(0.54 to 0.54)	(0.54 to 0.53)	(0.54 to 0.55)	(0.54 to 0.51)
Difference ± 90% CL	0.00 (± 0.1)	-0.02 (± 0.1)	-0.01 (± 0.02)	-0.03 (0 ± 0.01)
Descriptor	*Possibly trivial* ↓	*Likely moderate* ↓	*Unclear*	*Very likely moderate* ↓
10 m sprint (s)	-	(1.89 to 1.95)	-	(1.89 to 1.96)
Difference ± 90% CL		0.05 (± 0.06)		0.07 (± 0.05)
Descriptor		*Most likely trivial* ↑		*Likely moderate* ↑
Well-being (AU)	-	(18.78 to 17.33)	-	(18.78 to 16.56)
Difference ± 90% CL		-1.44 (± 1.61)		-2.22 (± 1.77)
Descriptor		*Likely small* ↓		*Likely moderate* ↓

***Note*:** Threshold probabilities for a substantial effect were: 0.5% most unlikely, 0.5–5% very unlikely, 5–25% unlikely, 25–75% possibly, 75–95% likely, 95–99.5% very likely, >99.5% most likely. Thresholds for the magnitude of the observed change in each dependent variable were determined as the within-participant s x 0.3, 0.9 and 1.6 for a small, moderate and large effect, respectively. Cohen's *d* effect sizes were classified as: trivial <0.2, small 0.2 - 0.6, moderate 0.6–1.2, large 1.2–2.0, and very large >2.0 (Hopkins, 2006).

Table 5.3: Mean time played, % HR max, and sRPE for all matches

	DAY 1		DAY 2	DAY 3		DAY 4		DAY 5	
Score Eng – opposition	**Match 1** 6-27	**Match 2** 6-34	**Match 3** 10-28	**Match 4** 7-31	**Match 5** 9-42	**Match 6** 13-39	**Match 7** 10-37	**Match 8** 12-41	**Average of matches**
Time played (min) ***n*= 14**	16:54 ± 16:26	16:33 ± 9:40	19:33 ± 9:55	18:42 ± 8:40	15:08 ± 11:19	25:14 ± 14:09	24:49 ± 17:50	25:47 ± 11:03	20:20 ± 4:19
Mean % HR max (*n*= 11*)	88.1 ± 6.7	89.2 ± 6.8	86 ± 7.9	86.9 ± 7.2	87.9 ± 6	83.8 ± 6.3	83.4 ± 6.4	80.1 ± 8.2	85.7 ± 2
sRPE ***n*= 14**	103.6 ± 120.1	118.1 ± 79.4	132.4 ± 88.8	122.5 ± 78.3	118.9 ± 96.1	186.1 ± 144.7	211.2 ± 157.8	193.6 ± 151.2	148.4 ± 41.6

Note: For time played and sRPE (*n*= 14), whereas mean % HR max represents an average for players who wore HR monitors for at least one half of the match (*n*= 11*). As not all players wore HR monitors for all matches, a between-match comparison is not appropriate. Eng = England.

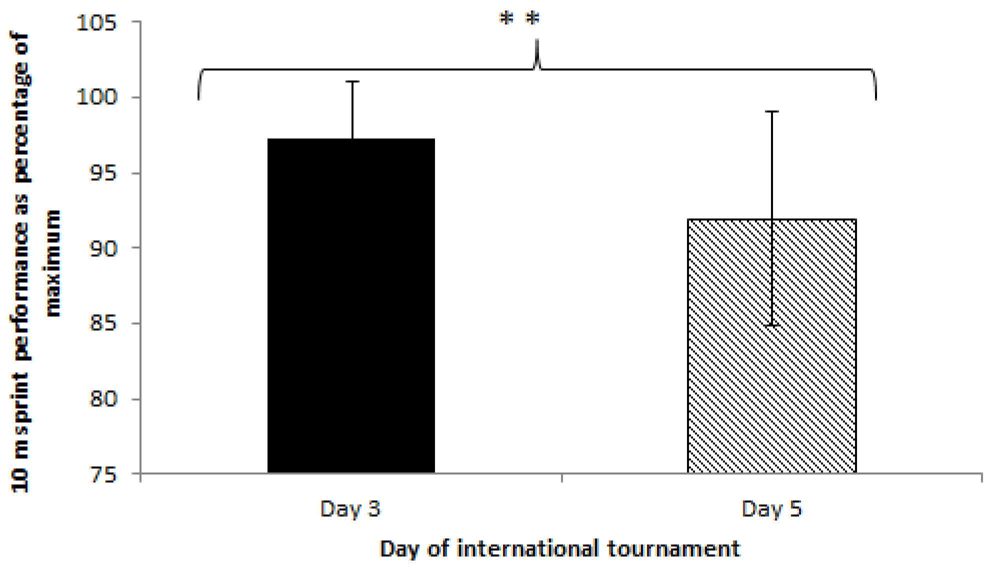
5.3.2.1 Neuromuscular and well-being responses

Flight time during CMJ did not differ between the eight matches (*P* = 0.06). Values ranged from 0.54 s – 0.56 s. Sprint times increased during the tournament, with values of 1.84 ± 0.07 s for day one, and 1.89 ± 0.06 s and 1.98 ± 0.12 s for day three and day five, respectively (*P* < 0.001). Large negative effect sizes were evident at day three (*d*= -0.80, *P* = 0.03) and day five (*d*= -1.49, *P* = 0.018) when compared to day one, as well as between day three day five (*d*= -0.99, *P* = 0.018).

Well-being decreased from baseline on days two, four, and five (*P* = 0.008). Decrements in muscle soreness were evident on days two, three, four, and five, and also between day three and five (*P* = 0.001). Fatigue also showed a tendency to increase during the tournament (*P*= 0.049), and was significantly different to baseline on day four (*P* = 0.04). Results showed no differences in sleep quality, stress, or mood during the tournament (*P* > 0.05). All *P* values and magnitudes of change are represented in Table 5.4.

Correlational analysis revealed significant relationships (*P* < 0.05) between sprint performance and well-being (*r*= -0.45), and between sprint performance and muscle soreness (*r*= -0.35), whereas no correlations were observed for CMJ.

5.3 (a)



5.3 (b)

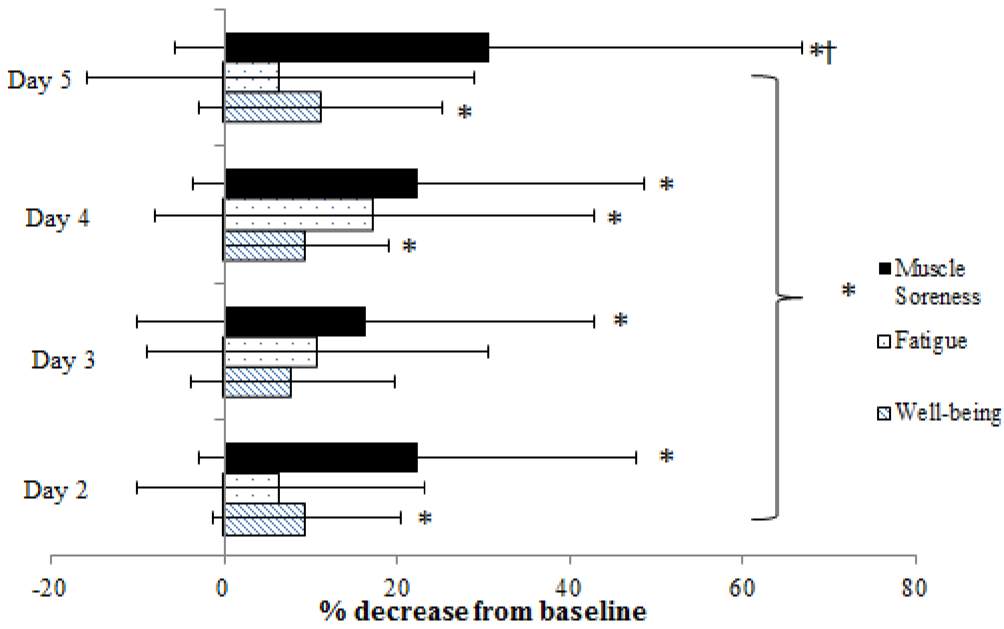


Figure 5.3 (a): Decrements in 10 m sprint performance as a percentage of baseline values at day three and day five (*n*= 12; *P* < 0.001). **(b):** Percentage decreases from baseline on days two, three, four and five in overall well-being, fatigue, and muscle soreness. * denotes significant difference to baseline. † denotes significant difference between day three and five for 10 m sprint, and † denotes significant difference from day three for well-being (*P* < 0.05; *n*= 12).

Table 5.4: Overall well-being, fatigue and muscle soreness responses throughout the tournament (*n*= 12)

		Day 1	Day 2	Day 3	Day 4	Day 5
Well-being	Values	20.08 ± 1.98	18.17 ± 1.53	18.5 ± 1.24	18.17 ± 1.03	17.83 ± 1.7
	P =	0.008	0.02	0.06	0.01	0.03
	Difference ± 90 CL	-	-1.92 (± 1.22)	-1.58 (± 1.35)	-1.92 (± 1.12)	-2.25 (± 1.61)
	Descriptor	-	*Very likely moderate* ↓	*Likely moderate* ↓	*Very likely moderate* ↓	*Very likely moderate* ↓
Fatigue	Values	3.83 ± 0.58	3.58 ± 0.52	3.42 ± 0.52	3.17 ± 0.84	3.58 ± 0.52
	P =	0.049	0.19	0.1	0.04	0.34
	Difference ± 90% CL	-	-0.25 (± 0.32)	-0.42 (± 0.41)	-0.67 (± 0.51)	-0.25 (± 0.45)
	Descriptor	-	*Unclear*	*Likely moderate* ↓	*Very likely moderate* ↓	*Unclear*
Muscle Soreness	Values	4.08 ± 0.67	3.17 ± 0.72	3.42 ± 0.79	3.17 ± 0.72	2.83 ± 1.03
	P =	0.001	0.014	<0.001	0.014	0.014
	Difference ± 90% CL	-	-0.92 (± 0.56)	-0.67 (± 0.60)	-0.92 (± 0.56)	-1.25 (± 0.77)
	Descriptor	-	*Very likely moderate* ↓	*Likely moderate* ↓	*Very likely moderate* ↓	*Very likely moderate* ↓

Note: Values are accompanied by *P* values derived from RM-ANOVA (day 1) and subsequent post-hoc analysis following a significant effect (days 2-5). Threshold probabilities for a substantial effect were: 0.5% most unlikely, 0.5–5% very unlikely, 5–25% unlikely, 25–75% possibly, 75–95% likely, 95–99.5% very likely, >99.5% most likely. Thresholds for the magnitude of the observed change in each dependent variable were determined as the within-participant s x 0.3, 0.9 and 1.6 for a small, moderate and large effect, respectively. Cohen's *d* effect sizes were classified as: trivial <0.2, small 0.2-0.6, moderate 0.6–1.2, large 1.2–2.0, and very large >2.0 (Hopkins, 2006).

Correlational analyses (*n*= 12) revealed significant relationship between sRPE and the decrement in 10 m sprint performance on day three (*r*= 0.64, R^2 = 0.42, SEE= 5.72, *P* = 0.03) and day five (*r* =0.80, R^2= 0.64, SEE= 3.47, *P* = 0.002). There was also a relationship observed between total playing time and decrement in 10 m sprint performance on day five (*r*= 0.87, R^2= 0.78, SEE= 2.67, *P* < 0.01) (see Figure 5.4).

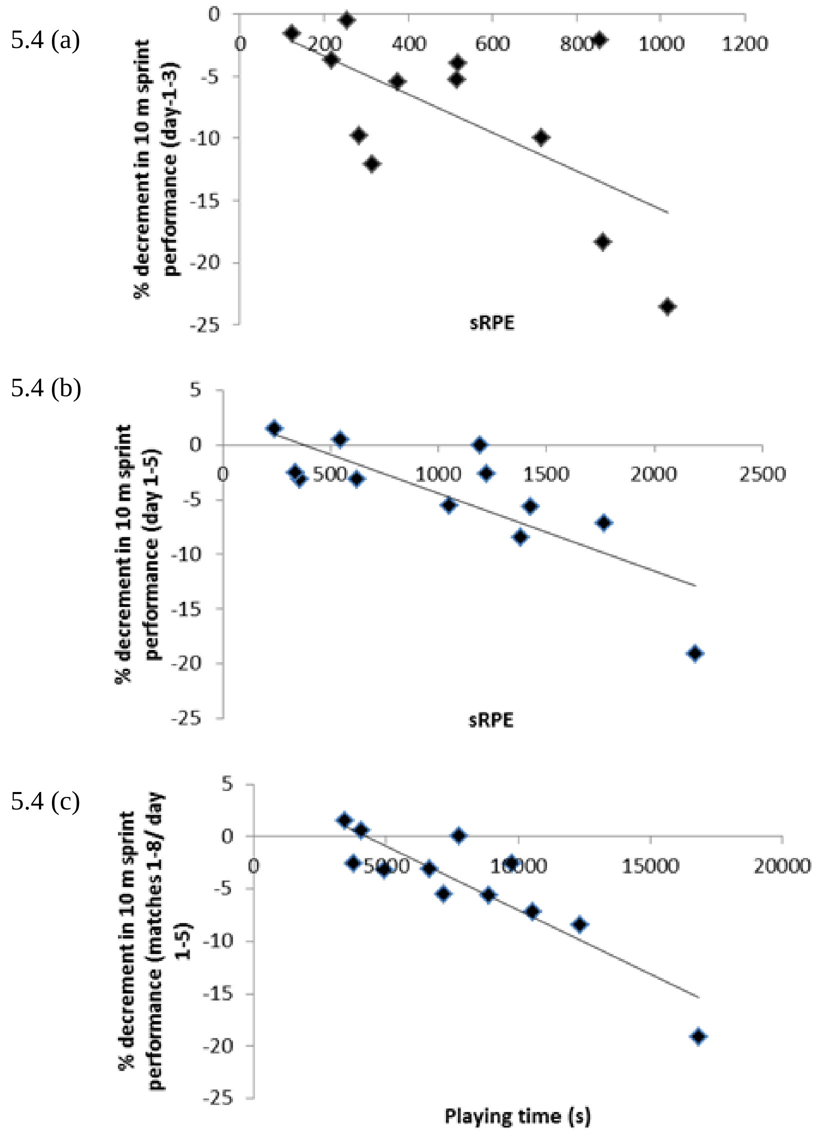


Figure 5.4 (a): Relationship between decrement in 10 m sprint performance and sRPE day three, **(b):** Relationship between decrement in 10 m sprint performance and sRPE day five, **(c):** Relationship between decrement in 10 m sprint performance and playing time day five (All *P* < 0.05).

5.4 Discussion

Key findings from the present study indicated that neuromuscular and perceptual fatigue increased in English male youth team handball players during a three-day training camp and a five-day international tournament. These were manifested as decrements of ~4% and ~8% in 10 m sprint for the training camp and international tournament respectively, reductions of 5% for CMJ flight time in the training camp, and an 11% reduction in well-being for both instances. Although previous studies have documented the recovery response in real-world scenarios (Johnston *et al.*, 2013a, Johnston *et al.*, 2013b; Rowsell *et al.*, 2009; Andersson *et al.*, 2008; Ronglan *et al.*, 2006), this study is the first to report these findings in young English male team handball players.

The gradual performance decrements in both scenarios agree with previous studies that have examined intensified competition and training in team sports (Johnston *et al.*, 2013a, 2013b; Rowsell *et al.*, 2009; Andersson *et al.*, 2008; Ronglan *et al.*, 2006). The intense scheduling demands during the training camp and the international competition meant that players were required to train and play without sufficient recovery, leading to a stress-recovery imbalance (Reilly *et al.*, 2008). Therefore, inadequate recovery caused a concomitant increase in residual fatigue and underperformance as the camp and competition progressed (Reilly *et al.*, 2008). Indeed, findings from this study are consistent with previous studies showing progressive declines in performance, resulting in overall lowest performances on the final day of competition (Johnston *et al.*, 2013a, 2013b; Ronglan *et al.*, 2006).

Sprint performance results from the training camp are comparable to those reported by Ronglan *et al.* (2006) showing reductions of 3.7% when female international players competed in three matches over three consecutive days. However, greater reductions of 5%

and 8% on days three and five, respectively, were observed during the international tournament for English players in this study. These findings suggest that under tournament conditions non-elite players experience greater neuromuscular fatigue than a training camp. Differences in magnitude between the two scenarios are likely to be because of the higher frequency of matches during the tournament within the same time-frame. Moreover, fatigue appears to be cumulative as the days of competition increase. Such results agree with existing evidence suggesting a progressive degeneration of neuromuscular performance when players are continually exposed to high-intensity exercise without appropriate rest (Johnston *et al.*, 2013a, 2013b; McLean *et al.*, 2010).

Reductions in CMJ performance during the training camp (4.9%) and international tournament (no change) were less than those reported in international female players during competition (6.7%, Ronglan *et al.*, 2006). The greater decrements observed by Ronglan and colleagues (2006) might be due to differences in the intensity of match play at higher standards of competition, potentially inducing a greater amount of jumping-specific neuromuscular fatigue. Indeed, this was England's first international youth tournament, for which they did not progress past the group stages, whereas the Norwegian female team hold Olympic (2008, 2012) and World Championship (2011) titles. In addition, results might be influenced by the shorter time periods played in this tournament which were around 20 minutes, compared to 28 minutes reported by Ronglan *et al.* (2006) and 30 minutes in this training camp study. Playing for shorter time periods might reduce the frequency of jumping actions, and thus potentially dampen the neuromuscular fatigue response for this particular movement, in comparison to longer playing durations.

Significant correlations between changes in sprint performance and markers of training load were observed during the training camp and the international tournament. Such correlations were not observed for changes in CMJ, suggesting that this parameter might be less sensitive to increases in training load. For the training camp, strong relationships were shown for sprint percentage decrement before match two with sRPE (r= -0.82, P = 0.02) and summated HR (r= -0.86, P = 0.01) taken after the first match. This suggests that players experiencing higher loads during a match were most affected by fatigue-related decrements in sprint performance the day after. Similar correlations between changes in sprint performance and sRPE were apparent on days three (r= 0.64, P = 0.03) and five (r= 0.80, P = 0.002) during the international tournament. These results highlight the usefulness of sRPE as a tool to indicate potential declines in performance in the days after a match. Total playing time and the decrement in sprint performance after the final match (day five) accounted for the strongest relationship (r= 0.80, P < 0.01), showing that greater playing times are largely indicative of cumulative declines in sprinting performance during tournament scenarios. Coaches would benefit from monitoring individual playing time and assessing its relationship with simple performance measures such as sprints and/ or sRPE in order to ensure adequate rest of particular players when required.

Ultra-structural damage to the muscle and the impairment of excitation-contraction coupling has been widely reported in the literature after intermittent team sport activities (Twist *et al.*, 2012; Twist & Sykes, 2011; McLellan *et al.*, 2010). The eccentric nature of team handball competition, involving repetitive high-intensity actions such as sprints, feints, jumps and throws, create a high force-to-activation ratio that place large stresses on the muscle fibres (Thorlund *et al.*, 2008; Ronglan *et al.*, 2006). Although the contribution of muscle damage was not directly assessed in this study, evidence taken from other intermittent team sports has shown post-match elevations in indirect markers of muscle damage, such as creatine kinase, alongside reductions in neuromuscular performance (Johnston *et al.*, 2013a, 2013b; Magalhães *et al.*, 2009; Andersson *et al.*, 2008). Moreover, detrimental responses for muscle soreness reported as part of the well-being questionnaire (training camp values of 3.33 ± 0.87 to 2.78 ± 1.2 on day one and three respectively; tournament values of 4.08 ± 0.67 to 2.83 ± 1.03 on day one and five respectively), and the reduction in markers of muscular function, support the presence of muscle damage as reported by previous studies (Twist *et al.*, 2012; Magalhães *et al.*, 2009; Twist & Eston, 2005).

The moderate decreases in well-being suggest that the camp and the international tournament had a negative impact on the psychological state of the players. These findings support previous studies that have reported impaired psychological well-being during periods with large increases in training load (Hadala *et al.*, 2010; Coutts *et al.*, 2007; Halson *et al.*, 2002). Moreover, that our study found significant decreases in well-being the morning after the first match for the camp (~16 h), highlights the ability for just a single match to negatively influence psychological responses. Such results might have also been exacerbated as England lost the first match (and all others throughout the tournament). Indeed, these findings support previous research recording impairment of athlete psychological state immediately after high-intensity exercise (Hadala *et al.*, 2010). Collectively, findings suggest that psychological well-being can be affected over a short time period and continue to progressively deteriorate during periods of increased training load. It is also important to note the large individual variability regarding the extent to which well-being deteriorated among players (11.48 ± 15.26% and 11.2 ± 14.06% for the training camp and tournament respectively), thus highlighting that some players may possess greater psychological abilities to cope with the demands than others. This advocates the potential usefulness for planning training camps such as this into the yearly schedule, which may aid the mental preparation of players before competitive tournaments. This is particularly important for teams like this who have not been previously exposed to such intense situations. Practitioners and coaches should aim to take an individualised approach to monitoring well-being status, providing appropriate support when required.

Decrements in sprint performance were associated with decreases in self-reported well-being and muscle soreness during the camp and tournament. This finding is in agreement with studies reporting correlations between perception of muscle soreness and neuromuscular performance measures after muscle-damaging exercise (McLean *et al.*, 2010; Twist & Eston, 2007). Similarly, Ronglan *et al.* (2006) recalled anecdotal evidence that decreases in neuromuscular function during a team handball tournament were associated with a concomitant rise in the players' perception of 'heavy legs'. Overall, these findings suggest increases in perceived fatigue and muscle soreness could have reduced central drive and contributed to neuromuscular fatigue. Central fatigue exerts its effects through a variety of mechanisms (Knicker *et al.*, 2011), including changes in the motor pathway and in the discharge patterns of muscle afferents, which is manifested via reduced motor drive being sent to the neuromuscular junction (Taylor *et al.*, 2000). Information derived from afferent sources including the exercising muscles and lungs, and the circulatory system interact with psychological inputs, which then act through the perceived exertion and/ or motor areas of the brain to modulate motor drive and behaviour (Knicker *et al.*, 2011). Indeed, using twitch interpolation, Rampinini *et al.* (2011) reported the decrement in sprint performance and maximal voluntary contraction (MVC) of the quadriceps after a soccer match to be largely influenced by central fatigue. Therefore, it is possible that increased match play and training without sufficient recovery resulted in a negative interaction that impaired the player's perception of well-being, contributing to altered neuromuscular output.

In conclusion, these findings indicate that the intense scheduling during the training camp and international tournament did not allow the team handball players sufficient recovery time, manifested as reductions in measures of neuromuscular performance and well-being. Given that many team handball tournaments require players to compete in multiple matches over a short period of time, the findings from this study are deemed useful for informing the coaching practices of English youth team handball players or developing nations who are not familiar with this competition scenario. As the duration between training sessions and matches is limited, practitioners and coaches should utilise this time appropriately to optimise recovery of the physiological and psychological systems (Reilly *et al.*, 2008; Tessitore *et al.*, 2008). Likewise, appropriate interchange strategies and selection of players based on physiological and psychological data collected during tournaments might help to limit player fatigue. Results highlight that there is an essential need to expose players to high-intensity training camps, in an attempt to replicate the demands of tournaments. Owing to the particularly large decrements in well-being, this may prove crucial to aid the mental preparation of players. As the training camp in this study appeared to be less intense than the international competition, coaches and practitioners should seek to use data from the international tournament to inform appropriate camp workloads for optimal tournament preparation.

CHAPTER 6:

THE INFLUENCE OF DIFFERENT WORK AND REST DISTRIBUTIONS ON PERFORMANCE AND FATIGUE DURING SIMULATED TEAM HANDBALL MATCH PLAY

6.1 Introduction

Match-related fatigue in team sports is typically defined as a decrease in high-intensity running from the first to second half of a match (Krustrup *et al.*, 2010; Sirotic *et al.*, 2009; Mohr *et al.*, 2003). For example, in team handball matches, fatigue has been reported as a 16.2 – 21.9% reduction in second half high-intensity running (Michalsik *et al.*, 2013a; Michalsik *et al.*, 2014b). This is also accompanied by a lower number of high-intensity actions in the second half, such as the frequency of stops, changes of direction, and one-on-one situations (Póvoas *et al.*, 2012). Due to the intense nature of team handball competition, i.e. repeated sprints, jumps, throws, side-cutting, changes of direction, accelerations, and body contact (Michalsik *et al.*, 2013a; Ronglan *et al.*, 2006), strategies that minimise fatigue are therefore essential to ensure that players can perform optimally during a single match or tournament (Nédélec *et al.*, 2012).

Strategies to limit match-related fatigue have primarily focused on minimising factors such as dehydration, glycogen depletion, muscle damage, and mental fatigue prior to, or after the exercise (Nédélec *et al.*, 2012). However, the manipulation of factors during matches, such as the distribution of player work and rest periods, has received considerably less attention despite its potential to have an immediate impact on team performance (Bishop & Wright, 2006). Effective management of player rotations could help to reduce physiological loading and subsequent fatigue throughout matches, thus limiting any potential decrease in performance (Karcher & Buchheit, 2014). In a recent study by Nicolo *et al.* (2014), intermittent exercise bouts of the same absolute intensity but with different work-to-rest ratios of 2:1 and 1:1 were performed to exhaustion. Despite no differences in the neuromuscular responses between conditions, differences in the metabolic demand resulted in a ~4 times greater time to exhaustion when work and rest times were equal. These observations have the potential to inform the interchange strategies employed by coaches to optimise player output during a match.

Anticipatory pacing, where an individual allocates appropriate physiological resources based on the known end point of exercise (Billaut *et al.*, 2011), might explain why individuals adopt a particular intensity during exercise. Using information provided on the proposed duration and end point can influence subjective ratings of fatigue, perceived exertion and muscle activation (Billaut *et al.*, 2011), thus potentially altering performance in the proposed exercise activity. Although the phenomenon of pacing strategies during continuous exercise performance have predominated research investigations (De Koning *et al.*, 2011; Abbiss & Laursen, 2008), more recent work has examined the role of pacing strategies during team sports (Black & Gabbett, 2014; Waldron *et al.*, 2013; Billaut *et al.*, 2010). Indeed, repeated sprint ability is altered in relation to the exercise end point, with individuals increasing muscle recruitment and mechanical output when a lower total work-load was anticipated, compared to (1) no knowledge of the end point, and (2) knowledge that there was a need to complete a greater workload (Billaut *et al.*, 2011). Analysis of work-rate in team sports has also shown that 'interchanged' players set higher pacing strategies, completing greater overall distances and high-intensity effort bouts in comparison to 'whole-match' players (Black & Gabbett, 2014; Waldron *et al.*, 2013; Carling *et al.*, 2010). However, contrasting findings in basketball suggest that there is no relationship between playing time and intensity (Bishop & Wright, 2006). However, this study only analysed starting players who completed the majority of the match, and thus disregarded the potentially different work-rates of interchanged players who performed dissimilar work and rest distributions. Collectively, these studies highlight the potential influence of work duration and knowledge of the exercise end point of exercise on exercise intensity during teams sport activity.

Team handball and other team sports such as hockey, basketball, American football, and Australian Rules football, allow an unlimited number of interchanges, making it possible for coaches to control durations of work and rest to optimise the performance of a team (Aughey, 2010). Having knowledge of the end point and duration of a particular playing bout and the rest period that follows could influence an individual's pacing strategy, allowing the player to manipulate their exercise intensity to increase the potential of competitive success (Black & Gabbett, 2014). Considering the higher work-rates found in interchanged players during team sport matches (Black & Gabbett, 2014; Waldron *et al.*, 2013; Carling *et al.*,2010), it might be beneficial to establish the impact of different player work and rest distributions on key team-sport skills such as sprinting, jumping, shooting, and repeated sprint performance, alongside physiological and subjective parameters. If coaches are better informed on the impact of work and recovery periods, it could contribute to enhanced interchange strategies, allowing more effective distribution of individual workloads to maintain optimal team performance (Aughey, 2010). By seeking to understand the relationship between time spent on the court and important parameters of performance, it might be possible to determine whether there is a maximal length of time players can compete for before the effects of fatigue become detrimental to performance (Bishop & Wright, 2006).

Given the considerable lack of research into this potentially valuable area, and the possible applied implications for a variety of team sports, the aim of this study was to establish the effect of two different interchange strategies on performance and pacing strategy during a simulated team-sports protocol, with the addition of team handball movements to increase suitability for the participant group.

6.2 Methods

6.2.1 Participants and procedures

After institutional ethical approval, eight outfield youth male handball players (age: 16.1 ± 1.0 y, stature: 1.82 ± 0.11 m, body mass: 69.3 ± 6.6 kg) were invited to participate in the study. Five played for the English national team (U16/ U18), and all players competed in the U18 Men's National English League. Participants provided written informed consent and completed a health screening questionnaire before taking part.

Table 6.1: Baseline performance measures. Values are mean ± standard deviation

Variable	**Result**
CMJ (cm)	34.5 ± 4.2
20 m sprint (s)	3.29 ± 0.04
Throwing velocity ($km \cdot h^{-1}$)	75.04 ± 6.08
Yo-Yo IR1 (m)	1449 ± 538
RSSJA	
10 m (s)	2.18 ± 0.10
Agility (s)	1.33 ± 0.36
25 m (s)	5.65 ± 0.16
CMJ (cm)	25.97 ± 2.73

RSSJA = Repeated Shuttle Sprint and Jump Ability test (Buchheit *et al.*, 2010), where values are average scores from six repetitions.

Using a randomised cross-over design, participants completed two conditions of a team sport simulation (Figure 6.1) with either long (LONG) or short (SHORT) work-to-rest bouts. LONG comprised 3 x 13:00 min periods of work, separated by 8:00 min rest between activity periods. SHORT comprised 5 x 7:48 min periods of activity, separated by 3:45 min rest between work periods. Absolute work time (39:00 min) and rest (16:00 min) periods were the same for both conditions. During rest periods, participants were asked to remain seated until required to resume the protocol. Total work and rest times were based on those employed by the England Handball Team during training camps and tournaments (Moss, personal observation). Participants were required make three visits, the first of which involved baseline testing of maximal counter-movement jump (CMJ), 20 m sprint time, throwing velocity, the Repeated Shuttle Sprint and Jump Ability test (RSSJA) and the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1). In the same visit participants were familiarised to the simulation, completing the protocol six times with instruction from the researcher. After a minimum of two days LONG and SHORT conditions were performed at similar times of the day (± 1 h) with 5 - 10 days between each. All players were accustomed to the performance tests as part of their regular monitoring procedures. Participants were asked to consume and record their habitual diet for 48 h before the first experimental condition, which they were asked to replicate for the second condition. Participants were asked to refrain from heavy exercise 24 h before each condition, and instructed that no caffeine was to be consumed during this period. All participants stated that they had adhered to instructions at the beginning of each condition.

6.2.1.1 Simulated Team-Game Protocol

Match performance was simulated using the protocol described by Bishop *et al.* (2001), which comprises movements and actions that replicate those observed in team sports (Figure 6.1). Participants completed a standardized warm-up, which included six circuits of the protocol (as recommended by Singh *et al.*, 2010) beginning at 50% maximum effort on circuit 1, with progressive increases to maximum effort on the final circuit. This was followed by a series of passing and shooting drills for ~5 min. The simulation involves sets of intermittent running around a circuit replicating the movement patterns observed in team sports, with three maximal sprints, an agility section, walking, jogging, striding and a deceleration to a stop immediately prior to a CMJ. Participants were also asked to complete extra team handball movements on specific circuits throughout the protocol. The number of times required to complete each specific movement was established based on previous research detailing the demands of team handball competition (Michalsik *et al*., 2013a; Povoas *et al*., 2012). This included jump shots, (9 attempts), and moderate intensity pushes (contact) onto the bump pad (20 attempts), which were distributed evenly over each bout and performed at the same time-points for each condition. The circuit was completed in pairs on a staggered start (~30 s apart). Each circuit lasted ~50 s, allowing ~10 s rest before the next circuit (on 1 min). Participants completed the circuit for the specified work period.

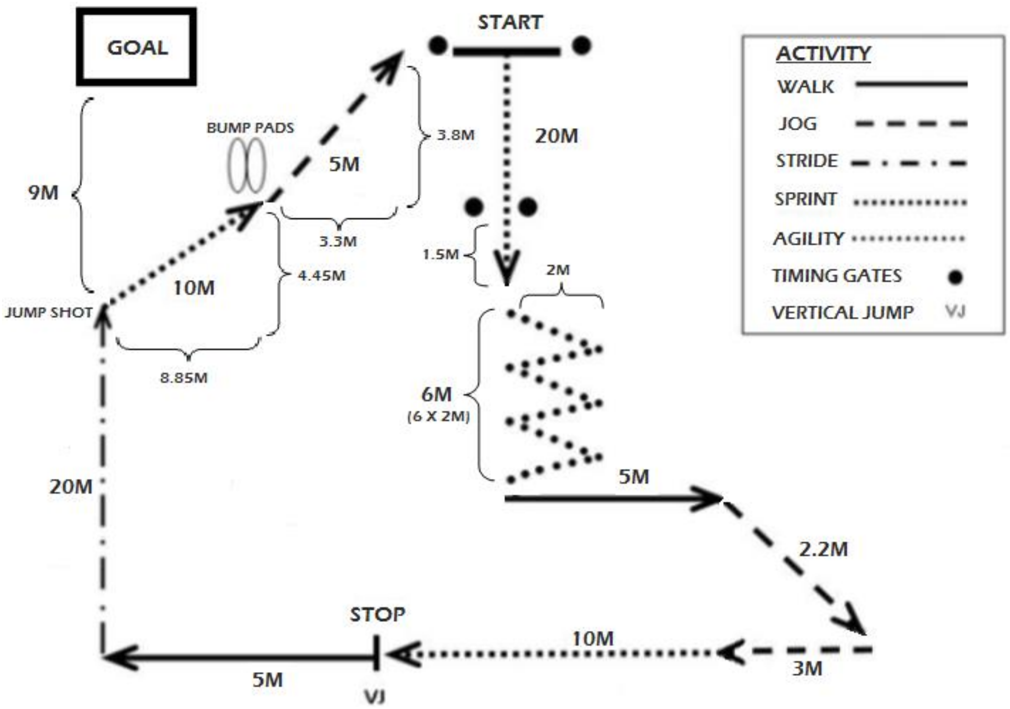


Figure 6.1: Simulated Team-Game Protocol modified from Bishop *et al.* (2001) (not to scale)

Measurements of heart rate (HR), 20 m sprint time, throwing performance, and CMJ performance were recorded throughout each protocol. In addition, blood lactate ([BLa]), blood glucose ([Glu]) and session rating of perceived exertion (sRPE) were recorded on completion, after which participants completed the Repeated Shuttle Sprint and Jump Ability test (RSSJA; Buchheit *et al.*, 2010) within 10 min of completing the trial. A schematic of timings of where each measurement was performed is shown in Figure 6.2.

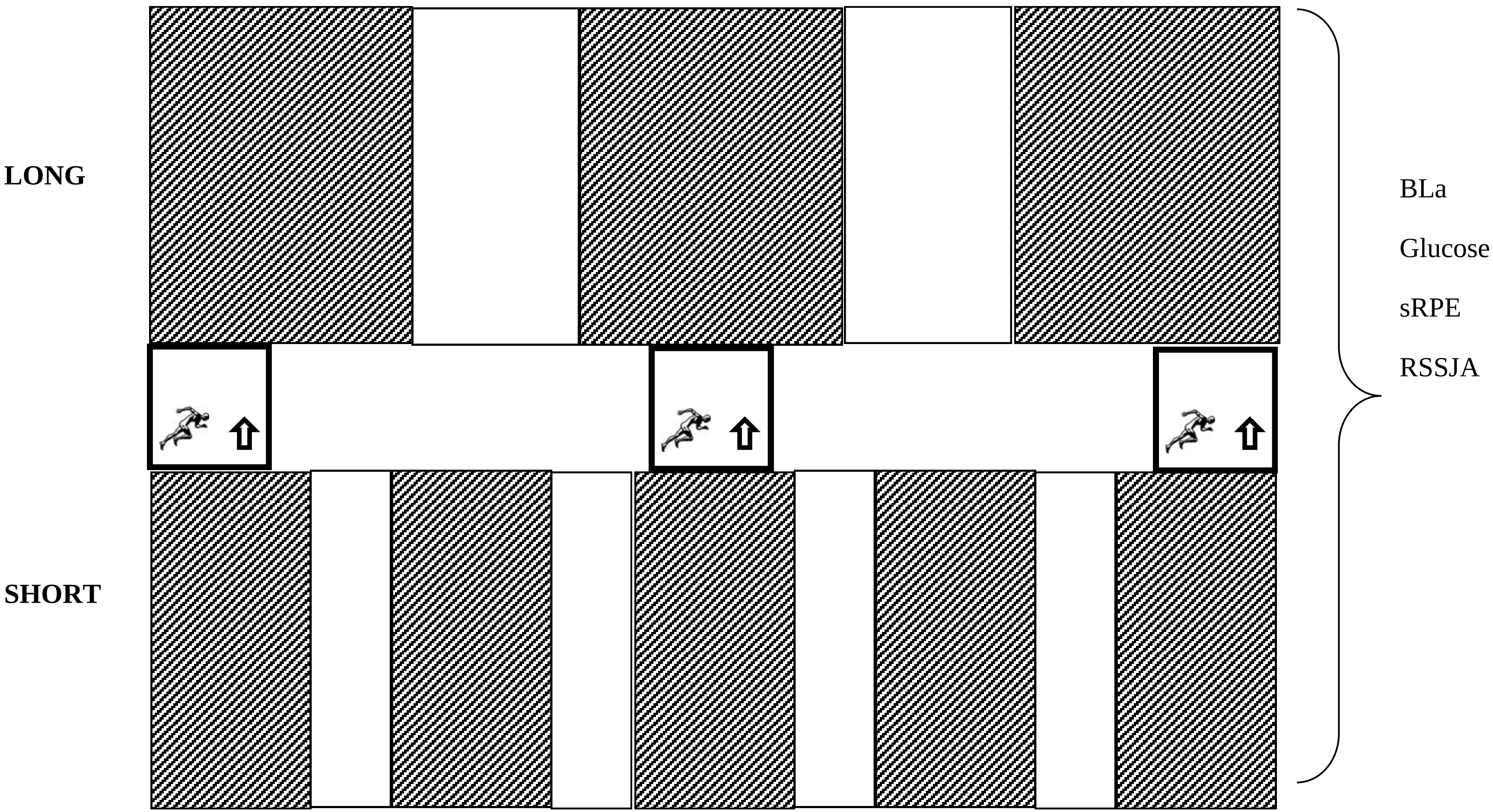


Figure 6.2: Work (shaded bars) and rest (clear bars) periods for LONG and SHORT conditions. Sprint performance  and CMJ  were taken during the first, middle and last six circuits of each condition. Throwing performance was taken from the first, middle and last three shots for each condition

6.2.1.2 Performance tests

20 m sprint time. Sprint performance over 20 m (CV = 1.19%) was measured during conditions using electronic photo cell gates (Brower Timing Systems, Colorado, USA) placed at 0 and 20 m in an indoor sports hall. Players were instructed to begin from a stationary standing start, with their foot behind the 0 m line. Participants performed three attempts with 2 - 3 min recovery in between, with the best attempt recorded for analysis.

Counter-movement jump. For the counter-movement jump (CMJ; CV = 2.4%), participants began in an upright position, and were told to flex at the knee to a self-selected depth and then jump for maximal height, keeping the hands placed on the hips throughout. Jump height was recorded from flight time using the equation of 9.81 x flight time^2 / 8 (Bosco *et al.*, 1983) and measured using an infrared timing system (Optojump, Microgate S.r.l., Bolzano, Italy) interfaced with a laptop. Participants performed three attempts with 2 - 3 min recovery in between, with the best attempt recorded for analysis.

Throwing performance. Throwing velocity (km·h^{-1}) was assessed using a velocity speed gun (Bushnell CBV00, Surrey, UK) held 1 m to the side of the goal post, and perpendicular to the player (CV = 1.88 - 2.22%). Players completed a maximal jump shot with 3-step run-up from 9 m, based on procedures of Vila *et al.* (2012). Accuracy during each condition was measured as success rate, based on the percentage of goals scored. Participants performed three attempts with 2 - 3 min recovery in between, with the best attempt recorded for analysis.

Yo-Yo Intermittent Recovery Test (Level 1). The Yo-Yo intermittent recovery test (Yo-Yo IR1; Krustrup *et al.*, 2003) requires performance of 2 x 20 m shuttle running bouts, interspersed with 10 s recovery at progressive speeds dictated by a pre-recoded audio signal. The final score was recorded as the total distance covered at exhaustion or after the second failed attempt to complete the shuttle running bout in the required time. Maximal heart rate

(HR_{max}) was recorded upon completion (Activio Sport System, Perform Better, BM-CS5EU, China) and used to represent an individualised absolute measure during matches.

Repeated Shuttle Sprint and Jump Ability test. This comprised six maximal 2 × 12.5 m shuttle sprints (~5 s) starting every 25 s. Participants had ~20 s recovery between sprints, where they were required to decelerate, perform a CMJ, and then an active recovery (covering 36 m ≈ running at 2.1 $m \cdot s^{-1}$). Averages were calculated for CMJ variables, and times for 10 m, agility (the time between 10 m, and the 2 x 2.5 m turn-around), and total 25 m. Average sprinting and jumping performance during RSSJA has previously shown good reliability (Buchheit *et al.*, 2010).

6.2.1.3 Blood lactate, glucose, and sRPE measures

Blood lactate ([Bla]; Lactate Pro, Akray, Kyoto, Japan) and glucose concentrations ([Glu]; ACCU-CHECK Aviva Blood Glucose Meter System, Roche Diagnostics, Mannheim, Germany) were measured after each condition. For each participant, the finger was cleaned with a medi-wipe to remove any contaminants and dried with a gauze swab. A softclix lancet device was used to puncture the site, with the first drop of blood wiped away. Light pressure was applied around the site with blood applied to the lactate (15 µl) and glucose (0.6 µl) strips for automatic analysis. Finally, sRPE using the 0-10 scale as described by Foster *et al.* (2001) was recorded immediately post-test and with verbal anchors placed on a numerical ratio scale, at the locations appropriate to their quantitative meaning. The sRPE is a modification of the category ratio (CR) RPE scale (Borg *et al.*, 1987), and has demonstrated good reliability in a number of exercise modes and across a range of exercise intensities (Herman *et al.*, 2006; Day *et al.*, 2004). In each instance, participants were showed the scale and were verbally prompted with "How physically exerting was that exercise?" Players were familiar with the measure, having used it regularly to monitor load during training.

6.2.1.4 Heart rate

Heart rate was recorded continuously (Activio Sport System,Perform Better, BM-CS5EU, China) throughout each condition. Peak and average values were expressed both as absolute ($b{\cdot}min^{-1}$) and relative to maximal heart rate (%HRmax). In addition, summated HR (AU) was calculated using the following equation (Edwards, 1993):

(*Duration in zone* 1 x 1) + (*Duration in zone* 2 x 2) + (*Duration in zone* 3 x 3) + (*Duration in zone* 4 x 4) + (*Duration in zone* 5 x 5).

6.2.1.5 Hydration testing and diet

Participants were asked to ensure that they were euhydrated prior to visits, and urine osmolality was measured upon arrival (Pocket Osmocheck, Vitech Scientific Ltd., Sussex, UK). Body mass (Tanita, BWB-800, Tanita Corporation, Tokyo, Japan) of all participants was taken immediately prior to each simulation condition in shorts only. Participants were able to drink water *ad libitum* but were asked to refrain from urinating during simulation conditions. On completion of simulation conditions, participants were asked to towel-dry themselves and body mass was recorded.

6.2.2 Statistical Analysis

Assumptions of sphericity were assessed using Mauchly's test of sphericity ($P < 0.05$), with any violations adjusted by use of the Greenhouse-Geisser correction. Separate 2 (condition) x 3 [(time) beginning, middle, and end of simulation] analyses of variance (ANOVA) with repeated measures were used to examine for any differences in 20 m sprint, CMJ, and throwing velocity. A Friedman test was used to examine for any differences in throwing accuracy over time (beginning, middle, and end of simulation), while a Wilcoxon test was used to analyse throwing accuracy between conditions. Beginning, middle, and end = the mean of the first six scores, middle six scores, and last six scores for each condition (20 m sprint, CMJ), respectively. Analysis for throwing variables comprised the means of three scores at each respective time point. Variables for the RSSJA were analysed using 2 (condition) x 6 (time) repeated measures ANOVA, using paired samples *t*-tests to follow up any significant effects. Separate paired-samples *t*-tests were used to assess differences in heart rate, [Bla], [Glu], sRPE, and time to complete and $m \cdot s^{-1}$ covered between conditions. Analyses were performed using SPSS v.19 (SPSS Inc., Chicago, IL), with the alpha level set at $P < 0.05$. Effect sizes and magnitude-based inferences (Batterham & Hopkins, 2006), were also calculated for all variables. Based on the 90% confidence limits, threshold probabilities for a substantial effect were: <0.5% most unlikely, 0.5 – 5% very unlikely, 5 – 25% unlikely, 25 – 75% possibly, 75 – 95% likely, 95 – 99.5% very likely, >99.5% most likely. The threshold for the smallest important change was determined as the within-participant standard deviation x 0.2, with 0.2 - 0.6 being small, 0.6 – 1.2 being moderate, 1.2 being large and >2.0 representing very large effects, respectively. Effects with confidence limits across a likely small positive or negative change were deemed unclear (Hopkins *et al.*, 2006). A predesigned spreadsheet (Hopkins, 2006) was used for all calculations.

6.3 Results

6.3.1 Changes in external, internal and performance demands between conditions

Despite no differences between conditions (F(1,7)= 0.39, P > 0.05), there was a main effect of time on circuit completion time (F(2,14)= 11.66, P= 0.001), and movement speed (F(2,14)= 9.53, P = 0.002). *Post-hoc* analyses revealed shortest completion times (P = 0.001) and greater movement speeds (P = 0.002) at the beginning compared to the end of each condition.

Changes in body mass from pre- to post-condition were similar for LONG (-0.17 ± 0.30 kg) and SHORT (-0.225 ± 0.25 kg; t(7) = 0.51, P > 0.05). There was a main effect of condition on 20 m sprint (F(1,7)= 7.420, P = 0.03), with overall sprints during the SHORT being faster than LONG. There was also a main effect of time on 20 m sprint time (F(2,14)= 7.803, P = 0.005), with *post-hoc* analysis revealing differences between the beginning and middle (P = 0.01) only. However, there was no condition x time interaction on 20 m sprint (P > 0.05). There were no differences in CMJ (F(1,7)= 0.38, P > 0.05) or throwing velocity (F(1,7)= 0.49, P > 0.05) between conditions, although magnitude-based inferences revealed 'likely small' differences that were indicative of higher throwing velocity in SHORT compared to LONG. There were also no main effects of time (F(2,14)= 2.35, P = 0.13) or condition x time interaction (F(2,14) = 0.95, P = 0.41) on CMJ, nor was there a main effect on time (F(2,14)= 1.31, P = 0.13) or condition x time interaction (F(2,14)= 0.094, P = 0.91) for throwing velocity (P > 0.05).

Throwing accuracy was not different between conditions at the beginning (z= -1.236), middle (z= -0.816), or end (z= -1.179, all P > 0.05), and there were no main effects over time for LONG (x^2= 4.16, P > 0.05) or SHORT (x^2= 0.33, P > 0.05).

Average HR corresponded to 85% HR_{max} in LONG and 83% HR_{max} in SHORT, while maximum values reached 92% HR_{max} for both conditions. Despite no main effect of condition on HR_{max} ($F(1,7)= 0.04$) average HR ($F(1,7)= 2.05$) or summated HR ($F(1,7)= 0.07$, all $P > 0.05$), there were 'likely small' lower average heart rate and summated heart rate in SHORT compared to LONG. A main effect over time occurred for average HR ($F(2,14)= 30.53$, $P < 0.01$), with *post-hoc* analyses revealing lower heart rates at the beginning compared to the middle ($P < 0.001$), but no further changes were apparent after Bonferroni adjustment (see Table 6.2). There was also a significant condition x time interaction ($F(2,14)= 13.72$, $P = 0.001$), with *post-hoc* analyses revealing lower heart rates for SHORT only at the beginning compared to the middle ($t(7)= -3.72$, $P = 0.007$), and end ($t(7)= -6.15$, $P < 0.001$), whereas no changes were found for LONG ($P > 0.05$, see Table 6.2). Post-condition measures showed that SHORT resulted in 'most likely moderate' lower sRPE ($t(7) = 5.61$, $P = 0.001$), in addition to 'most likely moderate' higher [Glu] ($t(7) = -2.64$, $P = 0.03$) compared to LONG. However, there were no differences in [Bla] ($t(7) = 1.11$, $P > 0.05$) between conditions. All data are shown in Table 6.3.

Table 6.2: A comparison of performance variables at the beginning, middle, and end of LONG and SHORT conditions

Performance variable	LONG	SHORT	% Difference (±90% confidence limits)	Descriptor (SHORT vs. LONG)
20 m sprint (s)*				
Beginning [M]	3.81 ± 0.12	3.90 ± 0.32	0.1 (± 0.1)	*Most likely trivial* ↑
Middle	4.01 ± 0.25	3.93 ± 0.29	-0.1 (± 0.1)	*Possibly moderate* ↓
End	4.06 ± 0.39	3.97 ± 0.38	-0.1 (± 0.1)	*Possible small* ↓
Overall	**3.97 ± 0.24***	**3.87 ± 0.27**	**-0.1 (± 0.1)**	***Likely small* ↓**
CMJ (cm)				
Beginning	27.52 ± 3.01	28.15 ± 2.79	0.6 (± 1.6)	*Unclear*
Middle	27.17 ± 3.28	26.70 ± 4.10	-0.5 (± 1.5)	*Unclear*
End	26.67 ± 3.38	25.65 ± 4.81	-1.0 (± 1.7)	*Possibly small* ↓
Overall	**27.03 ± 3.24**	**26.84 ± 3.50**	**-0.1 (± 0.1)**	***Unlikely small* ↓**
Throwing velocity (km·h^{-1})				
Beginning	70.01 ± 6.04	70.74 ± 7.52	0.5 (± 2.1)	*Unclear*
Middle	68.26 ± 6.16	69.67 ± 7.57	1.4 (± 3.2)	*Unclear*
End	68.86 ± 6.06	69.60 ± 7.69	0.7 (± 3.3)	*Unclear*
Overall	**69.04 ± 5.57**	**70.02 ± 7.40**	**1.9 (± 2.6)**	***Likely small* ↑**

Max HR (b•min^{-1})				
Beginning	179 ± 9	178 ± 9	-1.1 (± 3.5)	*Unclear*
Middle	179 ± 8	179 ± 8	0.0 (± 3.0)	*Unclear*
End	176 ± 8	178 ± 8	1.9 (± 2.0)	*Possibly small* ↑
Overall	**183 ± 8 (~92% HRmax)**	**182 ± 9 (~92% HRmax)**	**-0.8 (± 2.6)**	***Unclear***
Average HR (b•min^{-1})				
Beginning ^{M,E}	166 ± 10	164 ± 9^{M,E}	-2.1 (±3.6)	*Possibly small* ↓
Middle	170 ± 8	179 ± 8	-0.4 (± 5.4)	*Unclear*
End	170 ± 8	171 ± 8	0.6 (± 4.4)	*Unclear*
Overall	**169 ± 9 (~85% HRmax)**	**166 ± 8 (83% HRmax)**	**-3.8 (± 3.2)**	***Likely small* ↓**
Time to complete circuit (s)				
Beginning ^{E}	37.29 ± 2.74	37.44 ± 2.12	0.1 (± 1.7)	*Unclear*
Middle	40.12 ± 4.33	38.52 ± 2.60	-1.6 (± 2.6)	*Unclear*
End	40.75 ± 4.63	39.90 ± 2.76	-0.8 (± 3.7)	*Unclear*
Overall	**39.53 ± 4.0**	**38.26 ± 2.11**	**-1.3 (± 2.1)**	***Unclear***

Movement* speed *(m·s^{-1})	2.54 ± 0.20	2.51 ± 0.14	0.0 (± 0.1)	*Unclear*
Beginning ^{E}	2.37 ± 0.28	2.44 ± 0.18	0.1 (± 0.2)	*Unclear*
Middle	2.33 ± 0.30	2.38 ± 0.17	0.1 (± 0.1)	*Unclear*
End	**2.41 ± 0.26**	**2.47 ± 0.14**	**0.1 (±0.1)**	***Unclear***
Overall				

***Note*:** Beginning, middle, and end = the mean of the first six scores, middle six scores, and last six scores for each trial (20 m sprint, CMJ), respectively. Shooting velocity was taken from three scores for each of the time-points. M = difference to middle time-point, E = difference to end time-point. Magnitudes of change were classified as substantial increases (↑) or decreases (↓) when there was a > 75% likelihood of the effect being equal or greater than the smallest worthwhile change, calculated as 0.2 x between subject deviation, and classified as small 0.2 to 0.6; moderate 0.6 to 1.2; large 1.2 to 2.0; and very large 2.0 to 4.0 (Hopkins, 2006). Threshold probabilities for a substantial effect were: <0.5% most unlikely, 0.5 – 5% very unlikely, 5 – 25% unlikely, 25 – 75% possibly, 75 – 95% likely, 95 – 99.5% very likely, >99.5% most likely.

Table 6.3: Mean values for LONG and SHORT conditions

Variable	LONG	SHORT	% Difference (±90% confidence limits)	Descriptor (SHORT vs. LONG)
Summated HR (AU)	157.60 ± 20.83	150.27 ± 15.06	-6.3 (± 6.6)	*Likely small* ↓
[BLa] (mmol·l^{-1})	8.25 ± 6.74	5.23 ± 4.68	-3.0 (± 5.2)	*Unclear*
[Glu] (mmol·l^{-1})	4.98 ± 1.10*	6.06 ± 0.69	1.1 (± 0.8)	*Very likely moderate* ↑
sRPE (AU)	282.75 ± 34.57*	224.25 ± 45.45	-58.5 (± 19.7)	*Most likely moderate* ↓

***Note*:** * indicates significance between conditions; $P < 0.05$. Magnitudes of change were classified as substantial increases (↑) or decreases (↓) when there was a > 75% likelihood of the effect being equal or greater than the smallest worthwhile change, calculated as 0.2 x between subject deviation, and classified as small 0.2 to 0.6; moderate 0.6 to 1.2; large 1.2 to 2.0; and very large 2.0 to 4.0 (Hopkins, 2006). Threshold probabilities for a substantial effect were: <0.5% most unlikely, 0.5 – 5% very unlikely, 5 – 25% unlikely, 25 – 75% possibly, 75 – 95% likely, 95 – 99.5% very likely, >99.5% most likely.

The post-trial RSSJA test indicated differences in 10 m sprint time between conditions (*F*(1,7)= 6.862, *P* = 0.03), and a condition x time interaction (*F*(5,35)= 2.485, *P* = 0.05). *Post-hoc* tests revealed faster times for SHORT at sprint 4 (*t*(7)= 2.325, *P* = 0.05; 2.31 ± 0.15 *cf*. 2.21 ± 0.11 s for LONG and SHORT, respectively), and sprint 5 (*t*(7)= 4.051, *P* = 0.005; 2.31 ± 0.14 *cf*. 2.19 ± 0.08 s for LONG and SHORT, respectively; see Figure 6.3). Furthermore, SHORT resulted in 'likely moderate' faster times for sprints 2, 3 and 4, and 'very likely moderate' faster times for sprint 5 (CL: -0.1 ± 0.1 s for all) when compared to LONG. Total time for each 25 m sprint during the RSSJA also showed a significant condition x time interaction (*F*(2.74,19.20)= 3.133, *P* = 0.05). *Post-hoc* tests revealed faster times for SHORT at sprint 5 (*t*(7)= 2.708, *P* = 0.03; 5.98 ± 0.35 *cf*. 5.75 ± 0.26 s for LONG and SHORT, respectively; see Figure 6.4). This was supported by 'very likely moderate' faster times for sprint 4 and 5 CI: (-0.2 ± 0.2 s for both). There were no differences in agility time or CMJ performance between conditions (all *P* > 0.05).

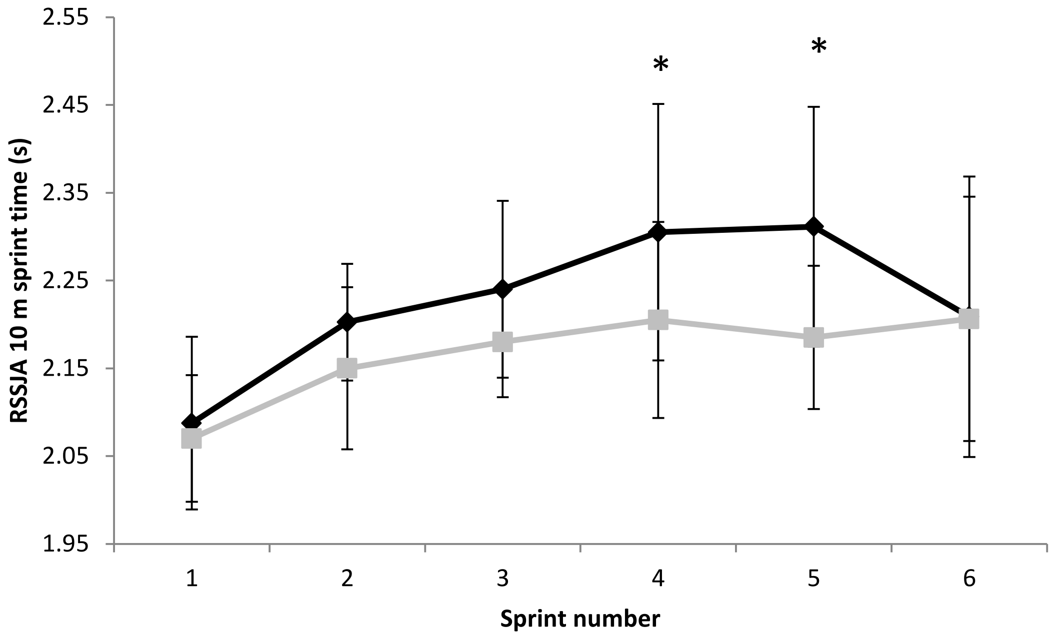


Figure 6.3: Mean ± SD 10 m sprint performance for LONG (black) and SHORT (grey) over 6 repeated efforts during the RSSJA test. * significantly different to SHORT ($P < 0.05$)

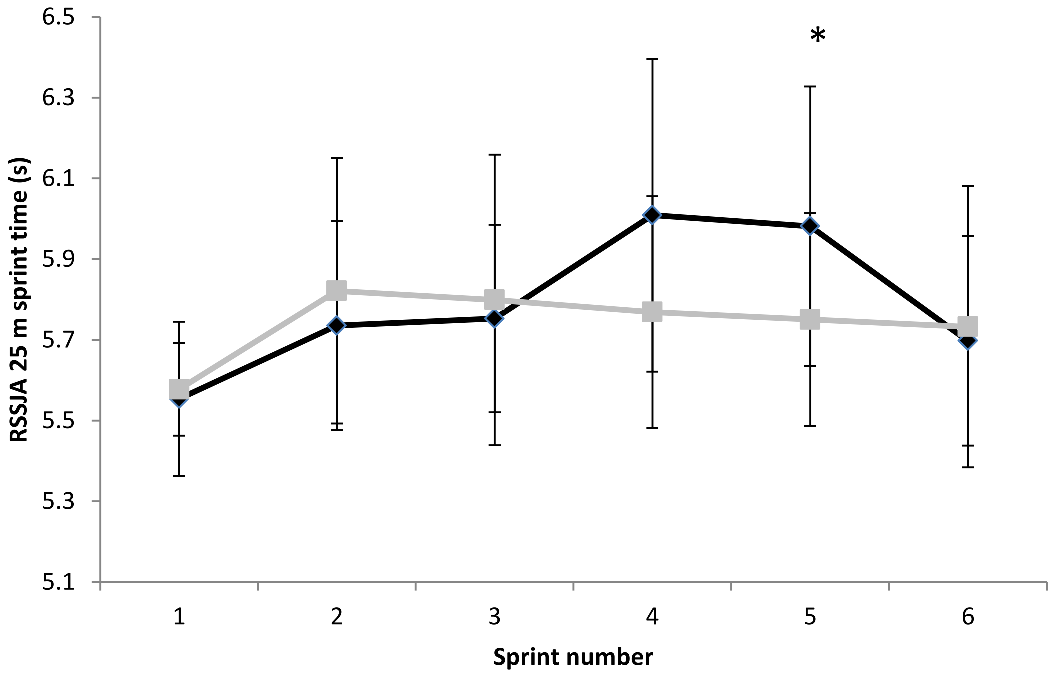


Figure 6.4: Mean ± SD 25 m sprint performance for LONG (black) and SHORT (grey) over 6 repeated efforts during the RSSJA test. * significantly different to SHORT ($P < 0.05$)

6.4 Discussion

This is the first study to investigate the influence of different work and rest distributions on performance and pacing strategy during a simulated team-sports protocol. Despite sprint time deteriorating progressively over the course of the simulation, a key finding was that faster sprint performances were maintained at the middle and end time-points when SHORT rather than LONG work and rest periods were adopted. Furthermore, reduced internal and external loading was apparent in SHORT, determined by lower average and summated heart rate, sRPE, and higher blood glucose concentrations. Repeated shuttle sprint running performance was also better preserved after SHORT work and rest periods, with moderate decreases in 10 m and 25 m sprint times. Collectively, these findings suggest that interchange strategies using SHORT work and rest periods (~8 min and ~4 min) as oppose to LONG periods of work and rest (~13 min and ~8 min) result in overall lower physiological load that leads to improved fatigue resistance and a better preservation of high-intensity movements throughout a match. This information could prove valuable to maximise player performance both during a match and tournament where multiple matches are played consecutively.

Although 20 m sprint time did not differ between conditions at the beginning of the simulation, these data suggest that faster sprint performance was 'practically meaningful' in the SHORT compared to LONG conditions at the middle (4.01 ± 0.25 s *cf*. 3.93 ± 0.29 s) and end (4.06 ± 0.39 s *cf*. 3.97 ± 0.38 s) time points. The faster sprinting performance in SHORT at the middle and end time points suggest that fatigue induced decrements in sprinting were more pronounced when work was distributed into three long periods, in comparison to five short periods. Indeed, previous research shows that the relative length of work time, and knowledge of its end point is integral to how players distribute intensity and inform pacing strategy (Black & Gabbett, 2014). Research in both rugby league (Black & Gabbett, 2014; Waldron *et al.*, 2013) and soccer (Carling *et al.*, 2010) recently reported that interchanged players adopted higher pacing strategies than whole-match players, evidenced by a greater amount of high-intensity activity during their involvement on the field. While these studies did not provide information relating to the average duration of work time in interchanged players, findings indicate the positive impact of shorter work-bouts on high-intensity activity. Therefore, awareness of the shorter work periods and knowledge that a rest period was in close proximity might have contributed to players setting higher pacing strategies that enabled faster sprints.

CMJ was not different between conditions or over time, suggesting that these movements were not limited by any fatigue induced by the simulation, and were not influenced by the differing duration of work and rest distributions. In the only study to monitor CMJ during matches, Hoffman and colleagues (2002) reported decrements at half-time, with values returning to baseline by the end of an American football match. Jumping performance after team-sport matches and simulations has been investigated by several studies, though findings are equivocal, being either unchanged (Krustrup *et al.*, 2010; Thorlund *et al.*, 2009; Hoffman *et al.*, 2002) or decreased (Twist & Sykes, 2011; McLellan *et al.*, 2010; Thorlund *et al.*, 2008; Singh *et al.*, 2010). That this study did not observe changes in CMJ performance, but did report deterioration in sprinting times might be explained by the nature of the protocol involving mainly running related movements with just one jump per circuit. Therefore, fatigue from the simulation did not affect jumping performance to the same degree as it did running. Secondly, it is possible that the lower training status of players from this study (CMJ = ~34 cm), compared to another team handball study (CMJ = ~38 cm, Thorlund *et al.*, 2008) influenced the magnitude of change. As such, having a lower jumping ability to begin with reduced the extent to which performance deteriorated, in comparison to players with a better jumping ability.

There were 'likely small' increases in overall average throwing velocity in the SHORT simulation condition, suggesting that a player's shooting performance might be compromised during more prolonged work bouts. Although restoration of adenosine triphosphate (ATP) in the shooting arm is likely to be resynthesized before completing the next shot (~3 min apart), it is possible that other determinants of shooting velocity could have been negatively influenced by fatigue during longer work bouts. Effective throwing performance is determined by the ability of a player to execute the correct technique, appropriately timing the movement of body segments, in addition to possessing and correctly executing strength and power of the upper and lower limbs (Chaouachi *et al.*, 2009; Gorostiaga *et al.*, 2005). Therefore, in consensus with the reduced physical ability of players to complete high-intensity sprinting in the LONG condition, it is possible that this finding can be explained by either reduced technical and/ or physical ability of participants to exert appropriate force during shooting performance. It can also not be discounted that players paced their maximal throwing effort in accord with the time of the forthcoming rest period as previously suggested (Black & Gabbett, 2014). As such, players might have worked harder in the SHORT condition in anticipation that a recovery period was within close proximity.

Players were able to maintain throwing accuracy regardless of condition or time. In contrast with results from this study, previous research has reported gradual declines in throwing accuracy over time (Zapartidis *et al.*, 2010; Zapartidis *et al.*, 2007). One explanation for these discrepancies might be due to the measure of accuracy used in this study, which was simply a measure of 'successful' (the ball entering the goal) or 'unsuccessful' (the ball being off-target). In comparison, Zapartidis and colleagues (2010; 2007) used the deviation of the centre of the ball from a pre-determined target, thus establishing a measure that was more sensitive to changes in performance. Considering that players are required to execute precise shot placement during matches, implementation of more sensitive measures might be of greater practical significance when monitoring the impact of work and rest periods over time.

Only small increases in heart rate were observed in the LONG (~85% HRmax) compared to SHORT (~83% HRmax) simulation. As the participants completed each work bout for ~5 minutes longer in the 'LONG' exercise condition, this probably explains the small difference. Indeed, coupled with day-to-day variation, increased cardiovascular drift in the LONG condition means increases in heart rate occurred to offset parallel decreases in stroke volume and mean arterial pressure (Coyle & Gonzalez-Alonso, 2001).

Despite the same exercise time in both conditions, the session rating of perceived exertion was higher immediately after completion of the LONG compared to SHORT simulation. Perception of effort is a major component of fatigue (Enoka & Stuart, 1992) and therefore might be an important determinant of performance during competition. Accordingly, these findings indicate that the longer relative duration of work performed in each bout during LONG, with less frequent recovery periods caused perception of effort to increase by a greater magnitude than when work was broken down into shorter periods.

A higher perception of effort is known to influence exercise tolerance independently of afferent feedback from the cardiovascular, respiratory, metabolic and neuromuscular systems (for a review see Marcora *et al.*, 2009). In accordance with the psychological model of exercise tolerance (Marcora, 2009; Marcora *et al.*, 2008, 2009), individuals are said to withdraw effort when the task demands exceed the greatest effort they are willing to exert in order to succeed (potential motivation), or when the required effort is greater than their perceived ability (Wright, 1998). As such, it is possible that the greater perception of effort observed in the LONG condition could contribute to the more pronounced decrement observed in sprinting performance. Therefore, participants' knowledge that they would have to maintain performance for a longer period of time might have been interpreted as more challenging, leading to a subsequent down-regulation of effort during sprinting activity. This could have particularly important implications during matches, or periods of repeated play during tournaments, whereby the relationship between sRPE and percentage decrement in sprinting performance got stronger over the course of an international tournament (r= 0.64 – 0.80, refer to Chapter 5). Therefore, using shorter work periods might be useful for reducing a player's perception of effort and contributing to the maintenance of sprint performance during matches throughout tournaments.

Interestingly, higher blood glucose concentrations were observed at the end of SHORT compared to LONG condition. This greater availability of glucose might help to partly explain the greater maintenance of sprinting performance throughout the SHORT condition, as high-intensity work relies on plasma glucose tissue uptake for muscle glycogen oxidation (Van Loon *et al.*, 2001; Romijn *et al.*, 1993). However, whether a relationship exists between blood glucose and net muscle glycogen utilisation during intermittent exercise is unknown (Hargreaves *et al.*, 1997). Reasons for higher post-exercise blood glucose concentrations in the SHORT condition are unclear. During exercise, secretion of glucagon promotes the release of glucose into the blood from the liver via glucogenisis and glucogenolysis (Lavoie *et al.*, 1997). Although speculative, it might be possible that the different work and rest periods between conditions led to an altered response in these processes, and subsequent hepatic glucose production. However, the exact mechanism and relevance to muscle glycogen utilisation warrants further investigation.

The post-simulation repeated shuttle sprint and jump ability test revealed faster sprint times for the SHORT compared to LONG condition. These results highlight that players were able to limit fatigue-induced decrements in repeated sprint performance when performing SHORT work bouts. These results are relevant considering the well documented decreases in sprinting activities during the later stages of team sport matches (Michalsik *et al.*, 2013a; Póvoas *et al.*, 2012; Sirotic *et al.*, 2009; Ben-Abdelkrim *et al.*, 2008; Bangsbo & Mohr, 2005). Therefore, effective use of interchange strategies throughout matches might contribute to greater maintenance of repeated high-intensity activity and subsequent performance in the final stages.

Reasons for the poorer repeated sprint performance after the LONG condition are likely to be multifaceted. Although the link between blood glucose and muscle glycogen concentrations during intermittent exercise is currently unknown (Hargreaves, 1997), the finding that blood glucose concentration was significantly higher after the SHORT condition needs to be addressed in relation to repeated sprint performance. Inadequate concentrations of glycogen have previously been associated with poorer sprint performance in soccer (Krustrup *et al.*, 2006; Saltin, 1973), and a close relationship between muscle glycogen content and fatigue resistance in intermittent exercise is well established (Gollnick *et al.*, 1997; Bangsbo *et al.*, 1992; Pemow & Saltin, 1971). Research suggests that the impact of limited glycogen availability on performance is manifested through inhibited rates of ATP regeneration, causing inadequate production of muscle force (Ortenblad *et al.*, 2013; Sahlin *et al.*, 1998). Thus, it is possible that lower availability of blood glucose after the LONG condition had a negative impact on participants' ability to complete repeated sprint activity.

An interesting observation revealed that the pacing strategies employed to complete the repeated sprint test were different between conditions. While 25 m sprint times progressively deteriorated with an 'end spurt' in the final sprint after the LONG condition, participants were able to maintain performance in the SHORT condition. That participants were able to produce a similar 25 m time in the final sprint of the test suggests that effort and motivation plays an important role after fatiguing exercise. These findings agree with previous research, which reported that the ability to produce force using a maximal voluntary muscle contraction was not inhibited after exhaustive exercise (Marcora & Staiano, 2010). Moreover, these authors proposed that tolerance to complete an exercise task is negatively influenced by perceived effort (Marcora & Staiano, 2010). It is therefore possible that the much higher perceived effort reported after the LONG condition had a subsequent impact on their perceived ability and/ or motivation to complete the repeated sprint protocol to the best of their ability (Marcora, 2008; Marcora *et al.*, 2009; 2008).

In conclusion, this study has been the first to investigate the impact of different work and rest distributions on a variety of performance characteristics during an intermittent team game simulation. Shorter work and rest distributions (SHORT) appeared to provide a practically meaningful preservation of sprinting performance, both during and immediately after exercise when compared to longer work and rest distributions (LONG). These findings can be used to better inform coaches, enabling them to maximise the effective distribution of interchange strategies and aid overall team performance during matches (Aughey, 2010; Bishop & Wright, 2006). Furthermore, these findings would become more applicable to tournament scenarios whereby there is a need to maintain team performance for a prolonged period of time (Gruić *et al.*, 2006; see Chapter 5). By effectively distributing work-loads, through short but frequent bouts of work and rest, players might be better able to maintain sprinting and throwing activity, and experience lower perceived exertion. However, it is also appreciated that such an interchange process requires skilful management by coaches, who need to ensure that continuous interchanging of players does not affect the 'flow' or quality of match play.

CHAPTER 7:

CONCLUSIONS

7.1 Main findings

7.1.1 Key characteristics

The importance of both anthropometric and physical performance characteristics to elite team handball performance were reiterated in Chapter 3. That British female non-elite players differed unfavourably to international top-elite players in almost all measurements highlights the need to reassess current talent selection processes, particularly for ‘high performance’ related pathways. Stature was the main anthropometric factor that differed in British players compared to both elite and top-elite players, suggesting that greater emphasis should be placed on identifying taller players to train on ‘high performance’ programmes. Perhaps the most prominent need for improvement in performance related to throwing velocity, which differed from both elite (65 – 72 $km \cdot h^{-1}$) and top-elite players (81 – 83 $km \cdot h^{-1}$) by up to 27% in British females (55 – 60 $km \cdot h^{-1}$). Mean values for youth male throwing velocity ranged from 69 – 75 $km \cdot h^{-1}$ (Chapter 4 and 6), which is comparatively lower than elite standard performers. Slower velocities suggest poorer technique and lower strength and/ or power in the musculature of the upper and lower body, resulting in overall reduced throwing efficiency (Wagner *et al.*, 2010). Indeed, in accordance with allometric scaling theory (Schmidt-Nielsen, 1984), selecting taller players is likely to improve strength and power characteristics, highlighting that with increasing size, cross-sectional area of the muscle also increases to a greater extent (Van den Tillaar, 2002). In addition, previous research has shown a positive association between strength and power training with throwing velocity (Chelly *et al.*, 2010; Marques *et al.*, 2007; Granados *et al.*, 2007). Therefore, providing sessions that educate players and coaches on how to develop these essential characteristics is warranted. Such training could also have a positive impact on other movements requiring rapid production of force (e.g. maximal sprinting, CMJ, body contact) which also compare unfavourably to elite team handball play (Chapters 3 – 6). Moreover, allowing dedicated time to improving throwing technique could have positive implications for throwing ability in British players.

British youth female players are also disadvantaged to their top-elite counterparts in the ability to perform repeated bouts of high-intensity running (Chapter 3). This also appears to be a problem for youth males who perform a much lower number of high-intensity actions during match play when compared to literature on elite players (Chapter 4). As such, employing practices that improve high-intensity running bouts with frequent changes in speed are essential for British players. This might include both running- and resistance-based training.

7.1.2 Player responses to competition

Youth male league matches showed that players competed for ~36 min, spending ~94% of total playing time in low-intensity activities (Chapter 4). However, the high relative HR reported in matches (80 - 89% HR_{max}, Chapter 4 and 5) and analysis of movement demands (Chapter 4) highlights that a variety of anaerobic actions exert high physiological loading on players. Overloading the physiological system during training will better prepare players for the demands placed on them during matches. Therefore, training practices should aim to stimulate HR between 80 - 89% HR_{max} for up to 40 minutes in preparation for matches or tournaments (Chapter 4 and 5). This should also involve intermittent instances of very intense activity to stimulate HR to near maximal values in an attempt to prepare players for worst-case scenarios during matches. This should be implemented in the form of intense and repeated body contacts, or sprinting activities with fast accelerations and decelerations (Chapter 4 and 5). Improvement in player intermittent training status should occur, which might translate to a faster and more dynamic game for English players.

Although competing in a single match showed no negative effects on sprinting and jumping ability (Chapter 4 and 5), it appears that players were unable to maintain aspects of neuromuscular performance when multiple matches were played within a short time-period (Chapter 5). Of particular interest was the deterioration in well-being responses after a single day of competition, which then followed a progressive decline throughout the tournament. The concomitant increase in residual fatigue, lowered well-being and underperformance in key performance abilities warrant specific strategies to better manage player loading and provide support to players. Practitioners and coaches need to establish monitoring processes during intense schedules to assess individual performance and well-being status, and use this information to make informed decisions to maximise team performance and maintain player health-status. Owing to positive associations with sprinting performance, the use of session RPE and/ or monitoring playing time of individuals might also be used to expose players who are particularly susceptible to performance decrements, should neuromuscular function monitoring be impractical (Chapter 5).

From monitoring players over a single match simulation protocol, results from Chapter 6 showed that employing shorter periods of work and rest (~8 min, ~4 min) better maintained maximal and repeated sprint performance, while reducing players' perception of effort (sRPE). This has the potential to limit decreases in high-intensity activity during matches (e.g. body contact between the first to second half of matches found in Chapter 4). In addition, the lower physiological and perceptual loading reported in short periods of work and rest could prove particularly beneficial for players who are showing greatest deterioration in measures of neuromuscular performance and well-being throughout a tournament.

7. 2 Limitations

7.2.1 The training status of players in England

The lower ranking and poorer performances in players from England means that findings can only be generalised to this standard of team handball players. For example, the recommendations of Chapter 5 are only applicable to non-elite players with little or no previous exposure to intense schedules. Furthermore, it is unknown whether adopting short work and rest periods in elite players will induce the same performance and perceptual benefits found in non-elite players. Notwithstanding this limitation, it must be acknowledged that the primary objective of this thesis was to provide a sequence of studies to monitor and develop the practice and performance of English players.

7.2.2 The lack of positional analysis

Although it is appreciated that differences between positions are apparent in movement demands during matches (Póvoas *et al.*, 2014; Michalsik *et al.*, 2014b; Michalsik *et al.*, 2013a; Šibila *et al.*, 2004) and in a variety of physical characteristics (Vila *et al.*, 2012; Chaouachi *et al.*, 2009; Šibila & Pori, 2009), analysis concerning such differences was not conducted within this thesis. In Chapter 3, the large volume of data on a wide variety of measures made the presentation of data by position difficult. Indeed, the central aim of the study was to provide detailed analysis relating to differences between the standards of competition in an attempt to determine how British players faired in comparison. The small number of participants in Chapters 5 and 6 also made it problematic to provide a good representation of players from each position. Therefore results for Chapter 5 were generalised to all players competing in the training camp and international tournament in an attempt to gain an understanding of how the whole team responded to intensified competition, while Chapter 6 was only applicable to outfield players.

7.2.3 Study design

Chapters 3 - 5 in this thesis investigated the responses of team handball players in applied 'real-world' scenarios. Despite the ecological validity of such investigations, uncontrollable external constraints sometimes required the study aims to be adjusted. For example, coaches who agreed to take part in Study 1 (Chapter 3) allowed one single session for performance testing to take place. This meant that players were required to perform a variety of strenuous tests within a short period of time. Therefore, while attempts were made to standardise procedures, it is possible that performance scores in some tests could be underestimated owing to fatigue induced from the previous tests. The structure of matches during Chapter 4 allowed only 5 min intervals between halves, subsequently limiting the number of players who could be tested for this study. This was further compromised by testing only being permitted during the preliminary stages of the league. Moreover, by excluding the final stages of the league, it is possible that the most demanding stages were not accounted for in the analysis.

7. 3 Future directions

7. 3.1 Development of talent identification processes and model for player progression

That players from Great Britain compared unfavourably to their European counterparts in a variety of measurements warrants the reassessment and development of talent identification systems. Specifically, there is a need to: 1) identify methods and standards used to select players onto ‘high performance’ or ‘talent pathways’ and 2) provide the knowledge and expertise to progress players to a higher standard throughout their youth careers.

The establishment of standardised athlete profiles for selection onto ‘high performance’ or talent programmes is required to ensure that Great Britain/ England is investing in those athletes capable of competing at an elite standard. This should occur at three levels of performance, namely the ‘England Talent Pathway’, national team representation (England) and international team representation (Great Britain). There are currently no set criteria for selection onto these programmes, with individual coaching teams making decisions based on their own set of benchmarks and individual perceptions. Therefore to improve the standard of players being supported on these pathways, it is essential for more stringent and informative criteria to be outlined to coaches and support teams. While data from this thesis can be used to inform the anthropometric and performance characteristics needed for elite standard performance, requirements in other key areas relating to technical, tactical and lifestyle criteria rely on the expertise of coaches and practitioners. Through working together to establish progressive criteria for each area and standard of performance, it is hoped that the overall standard of ‘the English player’ will improve. This process is currently being developed with assistance from the national governing body; Sport England.

It is evident that meeting the criteria for acceptance on performance programmes is highly reliant on a player’s ability to develop those key characteristics at club level. As such, the club environment has the potential to play a major role in improving players to their full potential. By providing coaches with the key criteria used to select players onto talent and ‘high performance’ programmes, they can be more informed on how coaching practices can be guided to enable players to meet these aims. This should be accompanied by coach education and the provision of resources that outline methods for how targets can be met. This process requires a long-term investment to develop future team handball players in

England. However, its implementation would provide a structured system to guide coaches and players to achieve the key requirements for success at the elite level.

7.3.2 Development of a specific team handball protocol

Despite attempts to establish a team handball simulation protocol (Thorlund *et al.*, 2008; Zapartidis *et al.* 2007), a validated method that accurately represents the demands of team handball performance is not currently available. Although the team sports protocol used for Chapter 6 (Singh *et al.*, 2010; Bishop *et al.*, 2001) was adapted to better replicate the demands of team handball competition, further development is warranted. Producing a simulation protocol that is validated against match demands will enable the effectiveness of intervention strategies to be established with greater applicability to team handball competition.

7.3.3 Player management strategies over intensified competition

Chapter 6 revealed that using an interchange strategy which required players to compete for short work and rest periods had beneficial effects on maintenance of maximal and repeated sprint performance, alongside lower perceptual loading than long periods. Due to the progressive decreases in sprint performance and well-being when matches were played within a short time period (Chapter 5), it would be useful to investigate whether interchange strategies can limit such deterioration. Therefore, future research should use a handball-specific simulation protocol to investigate the physiological, neuromuscular and perceptual (sRPE and well-being) responses of team handball players when completing short or long interchange strategies over a number of days.

7.4 Chapter summary

The overall aim of this thesis was to investigate the physical, physiological and performance characteristics of English team handball players in order to develop effective strategies to improve performance. This objective was addressed through four empirical research studies. Before this thesis, there was no information available on players from England, making it very difficult to make accurate recommendations for development. Findings revealed key weaknesses in relation to anthropometric and physical performance characteristics for youth British female players. For the first time, values on the key requirements of youth female players competing at the top-elite standard were provided. This allows for useful comparison and benchmarks the very best players in the World. The movement characteristics performed by youth male players taking part in the Youth National League (Chapter 4) did not compromise neuromuscular function, and appeared to be less demanding than elite standard competition. Therefore, to improve the standard of performance within this league, players would benefit from training practices that increase the speed and intensity of match play. Chapter 5 revealed that strategies to limit the physiological and perceptual loading of players are required during periods of intensified training and competition. This was demonstrated by a progressive deterioration in both neuromuscular performance and well-being. This calls for monitoring tools to identify and support players most susceptible to performance decrements in such environments. Finally, Chapter 6 showed that by adopting different interchange strategies, it is possible for players to reduce fatigue-related decrements in maximal and repeated sprint performance, while limiting effort perception during matches. These results could prove useful for managing overall loading and fatigue in single match and tournament scenarios.

CHAPTER 8

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CHAPTER 9

APPENDICES

Appendix 1: Example participant information sheet

Participant information sheet

A comparison of anthropometric and physical performance characteristics between elite and non-elite team handball players

You are being invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Thank you for reading this.

What is the purpose of the study?

This project is being undertaken as part of a research project within the Department of Sport and Exercise Sciences at the University of Chester.

You are being invited to take part in a research study in cooperation with the University of Chester and the England Handball Association. The project is part of a series of studies investigating the physiology of elite team handball players, and will be conducted by Samantha Moss who is the lead sports scientist for the youth talent pathway and PhD candidate at the University of Chester. The broad aim of the study is to inform the GB talent pathway by identifying the anthropometric and physical peformance characteristics that are required in elite team handball players.

More specifically, the study will seek to compare the anthropometric and physical performance characteristics of youth players from England team handball squads with players from Europe (proposed nations: Denmark, Norway, Spain), as well as from an English rugby league academy squad and recreational hanbdall players from colleges and local clubs.

Why have I been chosen?

The study is seeking to investigate the anthropometric characteristics of youth players from handball, rugby league and recreational sports team players in males and females.

Do I have to take part?

It is up to you to decide whether or not to take part. If you decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the standard of care you receive in any way.

What will happen to me if I take part?

You will be measured for standing stature, body mass, eight skinfolds, five girths, and two breadths according to the protocols outlined by the International Society for the Advancement of Anthropometry (ISAK; Marfell-Jones *et al.*, 2006). Skinfold sites will be landmarked using standard ISAK procedures at: the triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, and medial calf on the right side of the body. All sites will be identified and measured using Harpenden callipers (British Indicators, Burgess Hill, UK). Girths will include forearm (relaxed), forearm (flexed and tensed), waist, hips (gluteal), and calf. Breadths will include the humerus and femur. From this information, somatotypes will be determined using standarized ISAK methods. Each anthropometic measure will be repeated 2-3 times. All measurers will be ISAK level one accredited, and are thus deemed competent to complete the measurements detailed.

Following this, you will complete the following tests: 20 m sprint test with 10 m split, maximal counter-movement jump test, repeated shuttle sprint and jump ability test (RSSJA), flexibility, throwing speed and accuracy, and the Yo-Yo Intermittent Recovery Test (level 1). Heart rate and final blood lactate concentartion will be taken during and after the Yo-Yo Intermittent recovery test, respectively.

If you are randomly selected to take part in the second stage of the study, you will be asked to attend one further session for one hour, where you will complete a handball simulation protocol (activities similar to matches). Performance will be measured throughout, and heart rate and blood lactate will be taken at various time points throughout the protocol.

What are the possible disadvantages and risks of taking part?

It is likely that you might experience some discomfort during Yo-Yo test. Blood sampling may cause some discomfort to the finger tip, and earlobe for a short time. When having anthropometric measurements taken, you are welcome to bring a guardian if it makes you feel more comfortable. However, this is not a requirement.

What are the possible benefits of taking part?

By taking part, you will be enabling researchers to gain a greater understanding of the anthropometric and physical performance characteristics needed to become a successful handball player. This will provide coaches and practitioners with valuable information to select talented players and aid the development of handball in England for future generations. Gaining information on elite handball nations will also enhance the design of optimal training strategies to improve team performance.

What if something goes wrong?

If you wish to complain or have any concerns about any aspect of the way you have been approached or treated during the course of this study, please contact Professor Sarah Andrew, Dean of the Faculty of Applied and Health Sciences, University of Chester, Parkgate Road, Chester, CH1 4BJ, 01244 513055.

If you are harmed by taking part in this research project, there are no special compensation arrangements. If you are harmed due to someone's negligence (but not otherwise), then you may have grounds for legal action, but you may have to pay for this.

Will my taking part in the study be kept confidential?

All information which is collected about you during the course of the research will be kept strictly confidential so that only the researcher carrying out the research will have access to such information. All data will be coded to ensure anonymity

What will happen to the results of the research study?

Results of this project might be published but any data included will in no way be linked to any specific participant.

You are most welcome to request a copy of the results of the project should you wish.

The data collected will be securely stored in such a way that only those mentioned above will be able to gain access to it.

Who is organising and funding the research?

The Department of Sport and Exercise Sciences at the University of Chester will be involved in organising and carrying out the study.

Who may I contact for further information?

If you have any questions about the project, either now or in the future, please feel free to contact Samantha Moss, Tel: 01244 513262 or Dr. Craig Twist, Tel: 01244 513441

Thank you for your interest in this research.

Appendix 2. Informed consent example

Informed consent

Title of the project: A comparison of anthropometric and physical performance characteristics between elite and non-elite team handball players

Name of researcher: Samantha Moss

Please tick the box if you are in agreement with the statement:

I have read and understood the Participant Information Sheet for the above study and have had the opportunity to ask the lead researcher any further questions	☐
I know that participation in the above study is entirely voluntary	☐
I know that I am free to withdraw from participating in the study at any time, without giving any reason and without my rights being affected	☐
I am aware that the results from the above study may be used in publication, but that my anonymity will be preserved at all times	☐
I understand that should I need to make a complaint, I may forward them on to: Professor Sarah Andrew, Dean of the Faculty of Applied and Health Sciences, University of Chester, Parkgate Road, Chester CH1 4BJ Tel: 01244 513055	☐
I agree to take part in the above study	☐

Name of participant	Date	Signature
Name of person taking consent (if different from researcher)	Date	Signature
Name of researcher	Date	Signature

Appendix 3: Pre-test health questionnaire example

DEPARTMENT OF SPORT AND EXERCISE SCIENCE
UNIVERSITY OF CHESTER
Pre-test Health questionnaire
(Please note that this information will remain confidential)

Name: ___________________________ Date of Birth: ___________ Age: ________

Resting Blood Pressure (mmHg): _____/_____ Resting Heart Rate (b.min^{-1}): ______

Project Title: A comparison of anthropometric and physical performance characteristics between elite and non-elite team handball players

Please answer the following questions truthfully and completely. The purpose of this questionnaire is to ensure that you are fit and healthy enough to participate in this research project and all physical activity involved.

1. Have you ever suffered from a serious illness or accident? YES ☐ NO ☐
   If yes, please provide details below.

____
____

2. Have you consulted your doctor in the last 6 months? YES ☐ NO ☐
   If yes, please provide details below.

____

3. Do you suffer, or have you ever suffered from any of the following:

	YES	NO
Asthma	☐	☐
Diabetes	☐	☐
Bronchitis	☐	☐
Epilepsy	☐	☐
High blood pressure	☐	☐

4. Is there any history of heart disease in your family? YES ☐ NO ☐

5. Are you suffering from any infectious skin diseases, sores, wounds or blood infections (i.e. Hepatitis B, HIV etc?) If yes, please provide details below. YES ☐ NO ☐

____
____

6. Are you currently taking any medication? If yes, please provide details below. YES ☐ NO ☐

____

7. Are you suffering from a disease that inhibits the sweating process? YES ☐ NO ☐

8. Is there anything to your knowledge that may prevent you from participating in the testing that has been outlined to you? If yes, please provide details below. YES ☐ NO ☐

____

Persons will not be permitted to take part in any testing if they:

- Have a known history of medical disorders (i.e. hypertension, heart or lung disease)
- Have a fever, suffer from fainting or dizzy spells
- Are currently unable to train because of a joint or muscle injury
- Have had a thermoregulatory disorder
- Have a gastrointestinal disorder
- Have a history of infectious disease (i.e. HIV or hepatitis B)

My responses to the above questions are true to the best of my knowledge and I am assured that they will be held in the strictest confidence.

Name: (Participant) _____________________________________ Date: ___________

Signed: (Participant) ____________________________________ Date: ___________

Name: (Researcher) ____________________________________ Date: ___________

Signed: (Researcher) ___________________________________ Date: ___________

MEDICAL QUESTIONNAIRE (PART B)

(PLEASE NOTE THAT THIS INFORMATION WILL BE CONFIDENTIAL)

In order to assess your recent physical condition, please complete PART B of the Medical Questionnaire. Please not that where participants are involved in assessment procedures that include repeat measurements over a period of time, you are requested to provide this information on each testing occasion.

	Yes	**No**
• Have you eaten in the last 2 hours? If Yes, please provide details	☐	☐

…………………………………………………………………………………………
…………………………………………………………………………………………

• Have you consumed alcohol in the last 24 hr	☐	☐

• Evaluate your diet over the last 24 hr. **Poor Average Good Excellent**

• Have you exercised in the last 24 h	☐	☐

If Yes, please describe below
…………………………………………………………………………………………
…………………………………………………………………………………………
……………………………………………………………………

• Is there any change in your physical condition in the last 24 h which might affect your performance in this test?	☐	☐

If Yes, please provide details

…………………………………………………………………………………………
…………………………………………………………………………………………
………………………………………………………………

Name: (Participant)………………………………………… Date:………………….

Signed (Participant): ……………………………………….

Name: (Researcher)………………………………………… Date:………………….

Signed (Researcher): ……………………………………….

Appendix 4: Ethical approval letter: Study 1 (Chapter 3)

Faculty of Applied Sciences
Research Ethics Committee

Tel 01244 511740
Fax 01244 511302
frec@chester.ac.uk

Samantha Moss
Department of Sport and Exercise Sciences
University of Chester
Parkgate Road
Chester
CH1 4BJ

3rd December 2012

Dear Samantha,

Study title:	**A comparison of anthropometric and physical performance characteristics between elite and non-elite team handball players.**
FREC reference:	**724/12/SM/SES**
Version number:	**1**

Thank you for sending your application to the Faculty of Applied Sciences Research Ethics Committee for review.

I am pleased to confirm ethical approval for the above research, provided that you comply with the conditions set out in the attached document, and adhere to the processes described in your application form and supporting documentation.

The final list of documents reviewed and approved by the Committee is as follows:

Document	Version	Date
Application Form	1	August 2012
Appendix 1 – List of References	1	August 2012
Appendix 2 – C.V. for Lead Researcher	1	August 2012
Appendix 3 – Participant Information Sheet	1	August 2012
Appendix 4 – Participant Consent Form	1	August 2012
Appendix 5 – Letter of Invitation	1	August 2012
Appendix 6 – Written permission to use facilities	1	August 2012

– England Handball Association		
Appendix 7 – Session Rating of Perceived Exertion	1	August 2012
Appendix 8 – Risk Assessment Form	1	August 2012
Appendix 9 – Pre-test Health Questionnaire	1	August 2012
Appendix 10 – C.V. for Additional Researchers	1	August 2012
Response to FREC request for further information and clarification		November 2012
Appendix 3 – Participant Information Sheet	2	November 2012
Appendix 4 – Participant Consent Form	2	November 2012
Appendix 8 – Risk Assessment Form	2	November 2012
Appendix 9 – Pre-test Health Questionnaire	2	November 2012
Appendix 11 – Signed written permission – Head Coaches of Levenger Elite and U16 Women, Norway	1	November 2012

With the Committee's best wishes for the success of this project.

Yours sincerely,

Dr. Stephen Fallows
Chair, Faculty Research Ethics Committee

Enclosures: Standard conditions of approval.

Cc. Supervisor/FREC Representative

Appendix 5: Ethical approval letter: Studies 2-3 (Chapters 4-5)

Faculty of Applied Sciences
Research Ethics Committee

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frec@chester.ac.uk

Samantha Moss
Department of Sport and Exercise Sciences
University of Chester
Parkgate road
Chester
Cheshire
CH1 4BJ

1st April 2011

Dear Samantha,

Study title:	***Physiological and perceptual demands of competition in elite handball players.***
FREC reference:	***512/11/SM/SES***
Version number:	***1***

The above application was considered by the Faculty Research Ethics Committee at the meeting held on 23rd March 2011.

Provisional opinion

The Committee would be pleased to give ethical approval of the research, subject to receiving a complete response to the request for further information set out below. Your response will be considered by Sohail Mushtaq (Lead Reviewer) and Simon Alford (Chair of the Faculty Research Ethics Committee) on behalf of the Committee.

Further information or clarification

- The Participant Information Sheet omits urine testing which must be included, plus measurement of weight.
- Remove standard of care from the Participant Information Sheet.
- Include urine samples in the Risk Assessment.
- Assuming the Researcher will not carry out all the procedures, identify who will assist.

- Clarify the power calculation and the maximum sample size to be used.
- Clarify how GPS will be used indoors.
- Points 4 and 5 on the Informed Consent can be removed as they are included on the Participant Information Sheet.
- Suggest that you add your University email address to the contact information on the Participant Information Sheet.
- Use University of Chester headed notepaper (see FREC web page).
- Amend the typographical error in Appendix 8, page 1 (purpose).

Please send **three copies** of your response template and revised documentation to the Committee, underlining or otherwise highlighting the changes you have made, and giving revised version numbers and dates to all documents.

Responses should be submitted within **two months** of the date of this letter. You **do not** need to resubmit your full application. Please send your response to Mrs. Jess Hitchcock, FREC Secretary, Centre for Public Health Research, University of Chester, Parkgate Road, Chester CH1 4BJ.

The Committee will confirm the final ethical opinion on the application within a maximum of 10 working days from receipt of an appropriate and acceptable response.

Membership of the Committee

The members of the Faculty Research Ethics Committee who were present at the meeting are listed on the attached sheet.

Yours sincerely,

Simon Alford
Chair, Faculty Research Ethics Committee

Enclosures: * List of names of members who were present at the meeting and those who submitted written comments
* Statistician's comments, where applicable
* Response to FREC template

c.c.: Supervisor
FREC Departmental/Centre Representative

Appendix 6: Ethical approval letter: Study 4 (Chapter 6)

DEPARTMENT OF SPORT & EXERCISE SCIENCES

MODULE SS5060

Research Proposal and Ethics Application 2012-13

Title:	The influence of different work and rest distributions on performance and fatigue during simulated team handball match play.
Students:	Paige Garvey and Kerry Wadmore
Supervisor:	Samantha Moss
Date:	03/04/13

The Area Ethics Panel has met and granted ethical approval for your study.

Your Supervisor is satisfied with your Research Proposal and you may now commence your study.

Dr. Craig Twist
Module Leader, Exercise Physiology

Professor Ken Green
Head of Department

Appendix 7: Descriptions and definitions of time-motion classification and key performance indicators

Categories and variables
Time-motion analysis (according to Póvoas *et al.*, 2012)
Standing: Motionless.
Walking: Motion, but with both feet in contact with the ground at the same time at some point during the gait.
Jogging: Motion with an airbourne phase, but with low knee lift.
Striding: Vigorous motion with airbourne phase, higher knee lift than jogging. i.e. 3-steps into shot.
Sprinting: Maximal effort with a greater extension of the lower leg during forward swing and a higher heel lift relative to striding.
Low-intensity sideways movement: Lateral movement that fulfils the criteria for standing, walking and jogging.
High-intensity sideways movement: Lateral movement that fulfils the criteria for striding and sprinting.
Backwards movement: Any motion backwards.
Key performance indicators (according to Póvoas *et al.*, 2012; Meletakos *et al.*, 2011; Ohnjec *et al.*, 2008; Gruić *et al.*, 2006).
6 m shot: A 6 m shot is every attempt made by a player to score a goal by projecting the ball at goal using their hand from on or in front of the 6 m line.
7 m shot: A 7 m shot is every attempt made by a player to score a goal by projecting the ball at goal using their hand from the 7 m line.
9 m shot: A 9 m shot is every attempt made by a player to score a goal by projecting the ball at goal using their hand from on or behind the 9 m line.
Push/shove against or received: When a player performs or receives a one or two arm push.
Clasp/grab against or received: When a player puts two arms around the waist and/or arms of a player.
Assist: A pass which sets up a goal.
Blocks: When the ball travelling towards goal is blocked by an opponent.

Interceptions: When a player intercepts a pass between two opponents.

Penalties conceded: When a player concedes a foul which is awarded as a 7 m throw.

Attacking and defensive technical errors: Individual actions that end with an unwanted conversion of the ball possession being the result of either a technical error or a rule infringement (making more than 3 steps while holding the ball, double-dribble, “carried” ball, forbidden body contacts, offensive foul, incorrect passes and poor ball receptions; all these enable the opponent to intercept passes or to perform throw-ins, etc.)
